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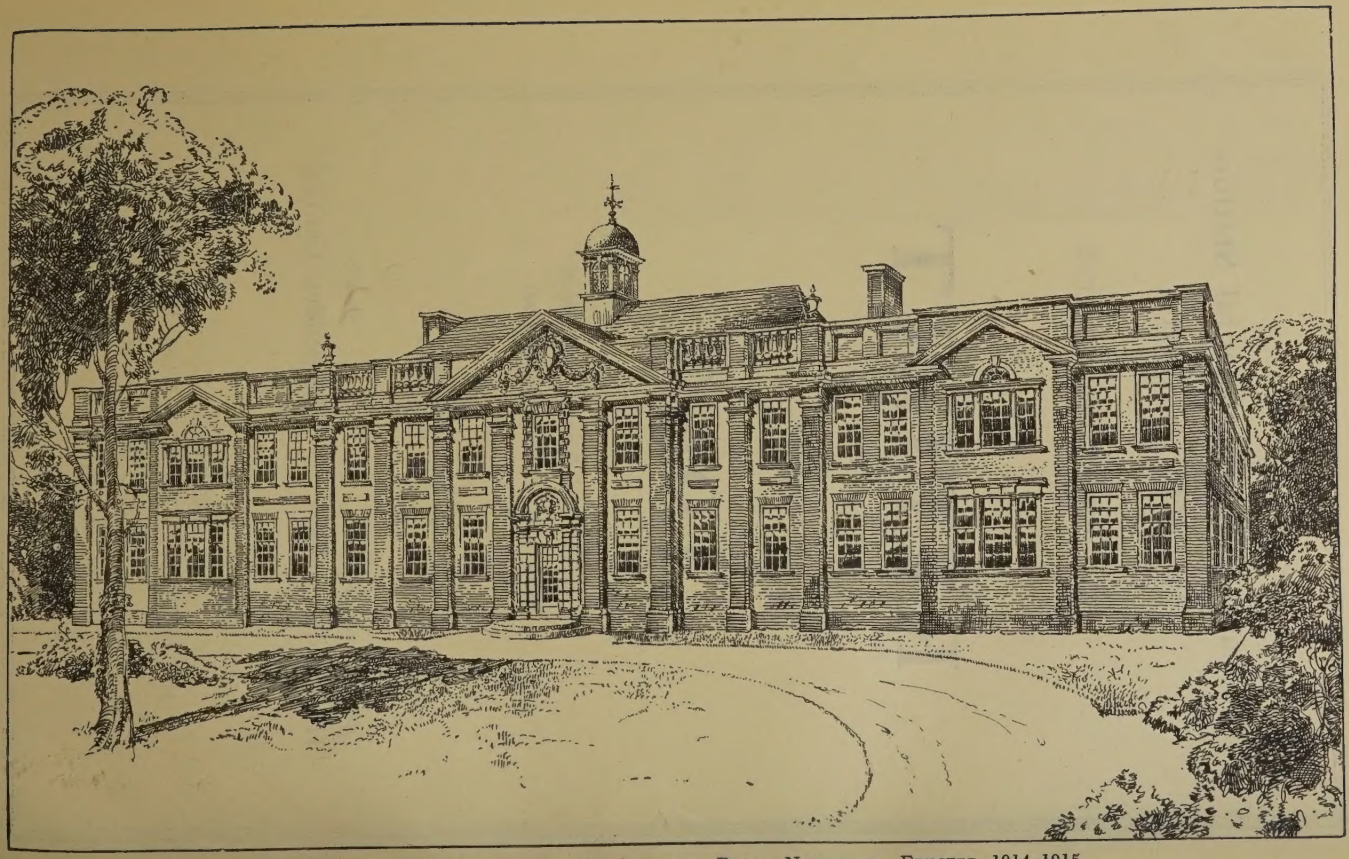

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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MURIEL E. DAVIES, B.Sc.(Wales)

The following spent varying periods as temporary workers at Rothamsted during 1960:

Australia: M. V. CARTER (Plant Pathology); **Barbados:** J. R. METCALFE (Entomology & Nematology); **Canada:** D. C. JORDAN (Soil Microbiology), R. D. TINLINE (Plant Pathology); **Denmark:** MRS. R. CHRISTENSEN (Nematology), H. A. JØRGENSEN (Plant Pathology); **Egypt:** A. K. HELMY (Pedology); **Eire:** P. C. CUNNINGHAM (Plant Pathology); **France:** M. G. DE GUIRAN (Nematology); **Gambia:** I. THORNTON (Field Experiments); **Germany:** A. AMBERGER (Chemistry), N. PFENNIG (Soil Microbiology); **Ghana:** A. ATTAFUAH (Plant Pathology); **Holland:** W. J. NIJVELDT (Entomology), MARGARETA M. D. TELLIER (Soil Microbiology); **India:** B. M. GUPTA (Soil Microbiology), KANWAR SINGH (Field Experiments); **Malaya:** SIEW KEE NG (Pedology); **Nigeria:** C. K. H. MARTINI (Plant Pathology); **Philippines:** C. R. LASMARIAS (Soil Microbiology); **Poland:** M. BIRECKI (Chemistry), K. KUZNIAR (Soil Microbiology); **Southern Rhodesia:** MRS. IRENA GILL (Statistics); **Sweden:** H. D. LJUNGGREN (Soil Microbiology), L. V. VON STEDINGK (Biochemistry); **Turkey:** TALIP ODEN (Insecticides); **Uganda:** W. R. MILLS (Statistics), D. A. PERRY (Nematology); **U.S.A.:** C. O. BERG (Entomology), L. V. KNUTSON (Entomology), L. R. KRUSBERG (Nematology), J. M. MACGREGOR (Chemistry), S. M. PADY (Plant Pathology); W. H. J. SILL (Plant Pathology), L. J. TYLER (Plant Pathology); **Yugoslavia:** S. HADZIVUKPVIC (Statistics), R. LOZANOV-

SKI (Field Experiments), M. MILIC (Field Experiments), MRS. RAJKA STRUNJAK (Soil Microbiology); **British Isles:** S. J. AIKINS (Entomology), VERONICA AIRD (Botany), JANE BALSHAW (Nematology), J. H. BEAUMONT (Chemistry), A. BOWLEY (Field Experiments), S. F. BUCK (Statistics), D. A. CADWALLADR (Entomology), ANN COLERIDGE (Insecticides), JOSEPHINE A. DARRAH (Plant Pathology), M. EASEBY (Insecticides), M. EVANS (Entomology), C. R. FIELD (Entomology), M. R. HADLER (Entomology), D. J. L. HARDING (Entomology), G. N. HARRINGTON (Plant Pathology), A. C. HASTIE (Plant Pathology), R. G. HEATHCOTE (Chemistry), C. B. M. HENDERSON (Chemistry), STELLA HERKLOTS (Biochemistry), M. IVORY (Field Experiments), E. J. JEWELL (Soil Survey), G. P. F. LANE (Plant Pathology), ANNE E. LEACH (Bee), D. S. MADGE (Entomology), D. MCGREGOR (Plant Pathology), JOAN RICHES (Entomology), D. A. RIJKS (Physics), P. ROY (Biochemistry), J. C. SEDDON (Plant Pathology), V. SISKIND (Statistics), D. J. WAGON (Statistics), J. G. WAINES (Plant Pathology), P. WALKER (Statistics), W. P. WALLACE (Physics), J. WARD (Botany), ANN WHITE (Plant Pathology), E. A. WYRLEY-BIRCH (Field Experiments).

SOIL SURVEY OF ENGLAND AND WALES

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A. Muir, Ph.D.(Edin.)

Deputy Head of Survey

D. A. Osmond, Ph.D.(Bristol), A.R.I.C.

Soil Surveyors

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B. W. Avery, B.Sc.(Reading)
E. M. Bridges, M.Sc.(Sheffield)
P. Bullock, B.A.(Birm.)
C. P. Burnham, B.A.(Cantab.), B.Sc.(Lond.)
B. Clayden, B.Sc.(Sheffield)
W. M. Corbett, B.Sc.(Edin.)
C. B. Crampton, Ph.D.(Bristol)
A. Crompton, B.Sc.(Leeds)
D. C. Findlay, B.A.(Cantab.)
C. J. Folland, B.Sc.(Bristol)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(Edin.)
C. A. Hodge, B.Sc.(Wales)
J. M. Hodgson, B.Sc.(Lond.)
R. A. Jarvis, B.Sc.(Dunelm.)
D. W. King, B.Sc.(Lond.), A.R.I.C.
D. Mackney, B.Sc.(Bristol)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
G. R. Suggett, B.A.(Leeds)
A. J. Thomasson, B.A.(Bristol)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.) (In Solomon Islands)
P. D. Jungerius, Ph.D.(Amsterdam) (In Ghana)
A. R. Stobbs, M.A.(Dunelm.) (In Sierra Leone)

Chemists

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Woburn Experimental Station

Officer in charge

C. A. Thorold, M.A.(Oxon.), A.I.C.T.A.

Chemist

T. W. Barnes, M.Sc.(Lond.), F.R.I.C.

Assistant Staff

G. Pearce, Q. D. Pope

Dunholme Field Station

Head of Field Station

R. Hull, Ph.D.(Lond.)

Scientific Staff

S. N. Adams, D.Phil.(Oxon.)
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R. A. Dunning, M.Sc.(Leeds), Ph.D.(Cantab.)
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INTRODUCTION

Sir John Bennet Lawes was experimenting before 1843, but the Rothamsted Experimental Station dates its foundation from this year because he then started his long and fruitful collaboration with J. H. Gilbert and laid down the classical wheat experiment on Broadbalk field. Lawes died in 1900 and Gilbert in 1901: they were succeeded as directors by A. D. Hall (1902–12), E. J. Russell (1912–43), W. G. Ogg (1943–58) and F. C. Bawden (1958–).

Until 1904, when the Society for Extending the Rothamsted Experiments was instituted, the work was paid for wholly by Lawes, at first directly and from 1889 from the fund of £100,000 with which he endowed the Lawes Agricultural Trust. In 1906 Mr. J. F. Mason paid for a bacteriological laboratory to be built, and in 1907 the Goldsmith's Company provided an endowment of £10,000. The first public money came in 1911 from the Development Commission, and since then government grants have been made annually; now the work is largely financed by annual grants from the Agricultural Research Council.

For long the experimental fields amounted to only about 50 acres, which were worked from the Rothamsted Home Farm, but in 1913 this farm of 250 acres was rented by the Station and the first farm buildings were put up on the site of the present range. In 1934 the Manor House, Home Farm, the site of the laboratories and various other parts of the estate, were bought by the Lawes Agricultural Trust for £35,000, raised entirely from voluntary subscriptions. Since then some additional land and other houses have been acquired, and the total area now owned is 580 acres, of which about 300 are suitable for field experiments. In 1952 the Manor House was opened as a hostel for members of staff and visitors.

The need to do field experiments on a range of soil types was early recognised, and since 1921 experiments have been done at many places away from Rothamsted. The taking over in 1926 of the Woburn Experimental Farm, which had been run by the Royal Agricultural Society of England, allowed experiments to be made simultaneously on heavy land at Rothamsted and light land at Woburn. In 1947 work on diseases of sugar beet became a part of the station's activities, and this has now developed into the Dunholme Field Station, Lincoln, at which the pests and manuring of sugar beet are also studied.

Although a range of problems was studied before 1900, the work was mostly chemical, and only few workers were engaged. With increasing numbers of staff in the early 1900s, the activities also widened and Departments of Botany, Soil Microbiology and Physics separated from the original Chemistry Department before 1914, and soon after the end of the First World War new Departments of Entomology, Plant Pathology, Insecticides and Fungicides, and Statistics were started. Except for additional posts for work on bees and on viruses and virus diseases, the Station's activities then

expanded little until the Second World War, when most Departments increased in size and others were added for Pedology (1945), Biochemistry (1947) and Nematology (1947). In 1946 Rothamsted also became the headquarters of the Soil Survey for England and Wales. From a total of 28 in 1912, the staff increased to 140 in 1943 and 471 in 1958. The Commonwealth Bureau of Soils, one of the ten bureaux that act as clearing centres for information on agricultural science, has been housed here since its establishment in 1929. The Station also accommodates visiting workers, many of whom use the special relationship with London University to register as internal students of the university for research degrees.

The building of laboratories, glasshouses and other ancillaries has roughly paralleled the growth of staff, but has always lagged behind, so that at least some of the departments are always overcrowded and the number of visiting workers that can be accepted is always much smaller than the number of applicants. Of the existing laboratories, the main block is the oldest and was opened in 1919; the North Building dates from 1924, the South Wing from 1940, the Nematology Building from 1947 and the West Building from 1955.

The Library

Until 1913, when Sir Henry Gilbert's books were given to the Station by his widow, the Library consisted almost entirely of Sir John Lawes's collection. It then grew rapidly in size and scope, until in 1917 it contained 10,000 volumes and in 1958 about 60,000 volumes. Its stock includes about 3,500 agricultural books published between 1471 and 1840, of which 13 are incunabula; 5,000 serial publications—1,700 of them current; 100 MSS. from the 13th century onwards, in addition to the Lawes and Gilbert papers; about 300 maps; and nearly 1,000 prints of livestock, mainly of the 18th and 19th centuries.

The following catalogues have been published: of serial publications (1954), of early agricultural books (1926, second edition 1940, supplement 1949) and of livestock prints (1958). The *Quarterly bulletin of the International Association of Agricultural Librarians and Documentalists* (1956–) is edited and published in the Library.

GENERAL REPORT

F. C. Bawden

H. F. Barnes, whose exceptionally productive work over 33 years did so much to establish the high reputation enjoyed by our Entomology Department, died suddenly in February. He was rightly known the world over as the authority on gall midges, but Barnes was no narrow specialist. Indeed, he was an excellent natural historian, and as evidence of his width of interest there is no need to cite more than his admirable work on slugs. Immensely industrious, and with an infinite capacity for taking pains to ensure the reliability of his conclusions, he was oblivious of normal working hours; when midges were active by day and slugs by night, most of the 24 hours were happily spent shrewdly observing these very different kinds of animals, whose behaviour and importance he did so much to elucidate. We mourn the loss, not only of an irreplaceable fund of knowledge but of an unique personality and an unusually loyal colleague, selflessly devoted to his work and to Rothamsted.

We also sadly report the death in June of R. K. Schofield, Reader in Soil Science at Oxford University, but a member of the Rothamsted staff for 28 years, during which he was head of the Physics Department for eight and of the Chemistry Department for two, in itself a testimonial to his versatility. A man of great originality and acute insight, his many novel ideas will long continue to influence the development of soil science. We shall miss his scientific inspiration, but shall also miss him because there will be no more of those delightful summer evenings when he played for us so tunefully and led us so ably and charmingly in country dancing on the Manor House lawn.

Fortunately, June also had its bright side. It brought the good news that Mary D. Glynne had been awarded the O.B.E., a welcome public acknowledgement of her many and varied contributions to agriculture and plant pathology during her 33 years at Rothamsted. H. G. Thornton, who retired in 1957 from the post of head of the Soil Microbiology Department, was made a Knight Bachelor in the same Honours List. 1960 was unusual in having a third Honours List, and the last day of the year was cheered by the news that W. C. Game's valued services for 50 years had been recognised by the award of the British Empire Medal.

C. G. Johnson's outstanding research gained him a special ("merit") promotion to the grade of Senior Principal Scientific Officer. F. Yates was awarded the Guy Medal in Gold of the Royal Statistical Society. F. C. Bawden was elected an Honorary Life Member of the Indian Botanical Society.

The Agricultural Research Council Unit of Plant Morphogenesis and Nutrition moved to Wye College, and we wish Dr. F. J. Richards and his colleagues well in their new home. As this unit they had been with us for only two years, but as the Research Institute of Plant Physiology they have worked at Rothamsted

since 1917, and we regret ending such a long, friendly and profitable association. We can make good use of the laboratories they vacated, but we would have preferred other ways of alleviating our overcrowding.

We have many plans to this end and for improving our glasshouses and other facilities, but unfortunately have few achievements to report. However, at the end of the year builders were on the site where there will be a small additional building to house some of our statisticians and a new Orion computer, which has been ordered and is promised for delivery late in 1962. It will not be too soon, for although the growing demands for computations were still met this year, our present machine gave much trouble, and a faster one, more versatile and easier to programme, is urgently needed to cope with analyses of surveys and the ever-increasing range of problems requiring complex analyses and computations.

Considerable progress was made in developing Broom's Barn, where a bore-hole was sunk successfully, roads were laid and the site prepared for laboratories and other buildings, for which tenders will soon be sought.

Visitors and visits

Prime among our several thousands of visitors were six " Visiting Groups " from the Agricultural Research Council. We thank the following gentlemen for giving of their valuable time to consider our affairs: Professor A. C. Aitken, F.R.S., Professor R. M. Barrer, F.R.S., Professor T. A. Bennet-Clark, F.R.S., Dr. A. S. Douglas, Dr. E. F. Gale, F.R.S., Professor Sir Joseph Hutchinson, C.M.G., F.R.S., Professor W. O. James, F.R.S., Professor Sir Hans Krebs, F.R.S., Professor O. W. Richards, F.R.S., Dr. K. M. Smith, C.B.E., F.R.S., Sir Geoffrey Taylor, F.R.S., Professor R. L. Wain, F.R.S., Professor C. W. Wardlaw, Professor V. B. Wigglesworth, C.B.E., F.R.S.

Of parties from overseas, the largest were four of delegates attending the Eighth International Grassland Conference; others included the Agricultural Committee of the Council of Europe, the European Barley Committee, the Commonwealth Entomological Conference, the Commonwealth Mycological Conference, delegates to the Tercentenary Celebrations of the Royal Society, to the Commonwealth Bureaux Review Conference and to the Second International Youth Science Fortnight. Individual visitors included the Ministers of Agriculture for Ceylon (Hon. C. P. de Silva), Eastern Nigeria (Mr. P. N. Okeke), Malaya (Hon. Inche Abdul Aziz bin Ishak), and Victoria, Australia (Hon. G. L. Chandler, C.M.G.) and the Minister of Natural Resources, British Guiana (Mr. B. Benn).

The many parties from the United Kingdom included the Nutrition Society and the Society of Applied Bacteriology. On 13 May the Rt. Hon. John Hare, M.P., then Minister of Agriculture, took luncheon in the Manor House with several other notabilities before formally opening the Ministry of Agriculture Plant Pathology Laboratory at Hatching Green.

Many of the staff travelled overseas, some to attend international congresses, others in response to requests from many differ-

ent countries for advisory visits or for help with specific research or development projects. We do our best to meet such requests, but they are now so frequent that regretfully most have to be refused.

The weather and crops

There was more rain than in any year since 1927, with the total at Rothamsted nearly 8 inches above the long-period mean. However, it was not uniformly distributed, and the first and second six months differed strikingly. The year started with field work unusually well forward, and the spring and early summer also favoured crops and farm operations. Indeed, the only problem was a shortage of grass from lack of rain during March to June, when we got 2·5 inches fewer than the long-period mean. Until the end of June conditions looked like rivalling those in 1959, with the promise of another early and easy harvest. The promise was fulfilled only with hay, of which an excellent crop was harvested early and without difficulty. July, August and September all had above average rain, and the cereal harvest was slow and difficult; many crops lodged, some sprouted in the ear, and our grain drier was taxed to capacity. Nevertheless, some plots yielded well; despite lodging, winter wheat sown early after potatoes yielded over 50 cwt./acre, nearly 20 cwt. more than when otherwise treated similarly but coming after another wheat crop.

Bad as conditions were for the cereal harvest, they later became worse. October, November and December produced over 8 inches of rain more than the long-period mean, and there were only 11 days on which less than 0·01 inches of rain fell. The year ended with many acres of potatoes still in water-logged ground, most fields still unploughed, only one lot of winter wheat drilled at Rothamsted and none at Woburn or Broom's Barn.

The contrasting weather of the first and second halves of the year was reflected in an unusual mixture of pests and diseases, for the first half gave us those usually prevalent in dry years and the second those usually prevalent in wet years. Some aphid species were active early in the year, and viruses spread rapidly in many early-sown crops of various kinds, and it seemed that the sugar-beet crop was again threatened by an early and severe attack of yellows. Fortunately this did not fully materialise, for predators of aphids were also plentiful in many places, which helped to check the infestation, and the weather from July onwards did not favour aphids. Nevertheless, there was again need to issue spray warnings, and most of the crops in south-east England were sprayed at least once. Perhaps significantly, yellows was much less prevalent in the south-east, which before crops were sprayed was always the worst affected area, than in the north and west. Experiments at Rothamsted and Broom's Barn again showed considerable benefit from spraying, though less than in 1959, when aphids were more numerous and active. A single well-timed spray increased yield of roots by over 2·5 tons/acre; at Broom's Barn two sprays were profitable, for unsprayed plots gave 36 cwt. of sugar per acre, and those sprayed once about 47 cwt., whereas those sprayed twice gave 52 cwt. The national average yield per acre is the highest ever recorded, but the

wet weather that helped to produce this record crop also made its harvesting an appalling task, still unfinished at the end of the year.

The continuous wet weather also produced some exceptional crops of potatoes, up to 26 tons of tubers per acre in some experiments at Rothamsted and an average of 21 tons with the variety Ulster Supreme at Woburn. And this despite an unusually severe attack of blight. Conditions so continuously favoured the spread of the fungus that spraying did not prevent blight, although it did prolong the life of the tops enough to increase yields by up to 4 tons of tubers per acre, the largest response to spraying we have recorded. A tin compound that showed promise against potato blight in the less testing conditions in 1959 again prolonged the life of the tops and increased tuber yields more than did copper or zinc fungicides. The tin compound was also effective against downy mildew in sugar-beet steckling beds. A high proportion of the tubers set by some potato varieties (more than a quarter of the King Edward crop) became infected by the blight fungus. Tubers are considered usually to become infected only by spores produced on the leaves and stems, but this year the fungus may have spread underground, because it was often found sporing profusively on tubers.

Irrigation

Of the many results on the great range of subjects described in the departmental reports and abstracts of published papers, only a few can be commented on here, and it may seem odd to choose irrigation after a year so wet as 1960. However, it is appropriate, not simply because even in this year early potatoes and grass benefited from irrigation, but for the good reason that the experiment at Woburn completed its third three-year cycle of crops and reached the stage when the practical results can be assessed. The number of farmers who irrigate their crops increases steadily, and many are guided in their practice by a Ministry of Agriculture Bulletin, published in 1954 and largely based on earlier Rothamsted work. This work suggested there would be need for irrigation when the rainfall for the months April to September was 3 inches less than the potential transpiration as estimated from ordinary meteorological measurements. Past records suggested that this would happen about seven years in ten at Woburn and still more often to the south and east. Actually, only five instead of six of the nine years of the experiment satisfied the specification of " irrigation need ". Of the twenty crops taken in these five years, all but two had their yields increased by watering at times and in amounts determined by weekly estimates of potential transpiration calculated from meteorological measurements made at Woburn. Of the sixteen crops taken in the four other years, only four had their yields increased by watering, and a few had their yields decreased when early irrigation was followed by heavy summer rain that caused leaching. In general, then, the original specification of irrigation need was substantiated, but it was hardly to be expected that all crops have the same water requirements, and the specification underestimates the need for grass and potatoes, is about right for beans and overestimates the need for sugar beet and cereals. The first three crops seem to suffer from lack of water at all stages of growth, whereas cereals suffer

mainly from a dry early summer and sugar beet from a dry late summer. Results with sugar beet have varied more than with other crops, and its water requirements are being studied in other more detailed experiments.

The large increases in yields of all crops in many years are evidence enough of the great potentialities irrigation has for increasing agricultural production in south-east England. Also, by showing how often benefits can be expected, when there is the need to water, how much water should be given and what benefits can be expected, the results remove the practice from the realms of guesswork and establish it on sound principles. Some uncertainties still remain. One is that watering is decided only by past weather, and irrigation will occasionally depress yields when watering is followed by heavy rain. This will not be fully overcome until weather forecasting reaches the stage of foretelling the weather for up to a week or more. This is not our problem, and meanwhile we must be content to know that the occasional depressions in yield are trivial compared with the many increases. What is our problem is that the interactions between watering and manuring differ with different crops; for example, barley yields are increased more by extra nitrogen than by extra water, and the less nitrogen it gets, the more it responds to irrigation, whereas wheat seems to need the water before it responds to extra nitrogen. Further work will doubtless explain this and show how manuring and watering should be combined to give the best results, not simply with cereals, which will probably be the last crops to be irrigated until there is a national plan to supply the south-east with abundant water, but with those that respond to watering more and more often.

The Woburn experiment more than justifies itself for its immediate value to agricultural practice, but it has value beyond this. Much of the work in the Botany and Physics Departments is done to find how plant growth and crop yields depend on the weather, and the continuing results from the irrigation experiment provide invaluable material for studying this problem.

Organic matter in soil

Our Report for 1958 stated that: " In some light soils organic matter seems necessary to maintain a structure, but at Rothamsted there is little evidence that it affects the growth of crops except through the supply of plant nutrients." This simple statement apparently disturbed some people who, to quote the editor of one journal, " fondly imagined that one of the major reasons for using organic matter on heavy soil, was to improve structure and that this was important to the well being of crops ". He then urged Rothamsted to start " some really sensible and conclusive experiments ".

Well, what is a sensible experiment can be a matter of opinion, but there is no doubt that we have been experimenting continually with organic manures longer than anyone else, and we have probably done many more experiments than anyone else to try and elucidate their beneficial effects, particularly of dung. Over a long time we have accumulated ample evidence of their value, but can only repeat that at Rothamsted there is no evidence that this

extends beyond their effects on the supply of nutrients. That arable crops can be grown continually without needing any more organic matter than is supplied by their ploughed-in residues is shown clearly enough by Broadbalk, where, after 117 years of growing only wheat, Plot 8, which gets only mineral fertilisers, yields as much as Plot 2, which gets 14 tons of dung annually. Only a glance is needed to see that the soil of Plot 8 differs from the rest, and the difference is what would generally be agreed on as an improvement, but wheat apparently fails to appreciate this. Even at Woburn, where poor soil structure can present problems, the yields of barley, sugar beet, wheat and potatoes recorded in the six-course rotation experiments are higher after 30 years during which only mineral fertilisers have been used than they were at the start of the experiment. Organic matter may be necessary, but it need not be applied as manures.

There are experiments at Woburn in which yields of some crops have been increased more by dung than by the mineral fertilisers given, but how to interpret these differences is by no means sure. As reported below, dung itself is a very variable material, even in its content of the three main nutrients, nitrogen, phosphate and potash, so ensuring that these contents are accurately matched by amounts of mineral fertilisers applied requires detailed analysis of each sample of dung. Dung supplies other elements than N.P.K., such as calcium, magnesium and sodium, any or all of which may increase yields. Also dung is ploughed in, whereas mineral fertilisers are usually broadcast or drilled, so nutrients are supplied at different positions in the soil. Current work on the Market-garden and Ley–Arable experiments suggests that the greater yields produced by dung than by mineral fertilisers may be largely explained by differences between the amounts of K applied and between the positions occupied by the K when applied as dung and as mineral fertiliser. Modifications to the Market-garden experiment should show whether dung is affecting crop growth in ways other than by the nutrients it supplies.

Even with such infertile and difficult sandy soils as some of the Forest Nurseries we get no evidence that organic manures are essential, as was at one time thought; when mineral fertilisers are given so that they supply plant nutrients in the same amounts as those in composts, the Sitka spruce seedlings grow as well as with compost.

Effects of organic matter on soil structure were shown by thin sections of soils with contrasting histories and by wetting and draining them to measure their stability and their permeability. Measurements of the pores in natural aggregates of soils after long-continued arable cropping suggested that root growth might be impeded in sandy soils but not in clay soils. Dung slightly increased permeability to water and stability on wetting, but its effect on sandy Woburn soil, even after many annual applications, was slight compared with the effect produced by a period under a ley. Even the effects from a three-year ley, however, were lost a year after ploughing the Woburn soil.

Freshly added organic manures or plant residues behave very differently from the decomposed organic matter in soils. The fresh materials provide a rich source of nutrients as they decompose, and

they usually improve soil structure, which may affect crop growth; but both effects are temporary. The decomposed organic matter contains plant nutrients that are released only slowly, and it lastingly modifies the physico-chemical properties of soil, but often without affecting the gross physical characters.

Soil organic matter is complex and variable, and it is vain to expect that conclusions about its effects on crop growth in one set of conditions will apply at all generally. Nor need all its effects be from its nutrient content or by changing soil structure. The quantity and quality of organic matter also largely determine the number and kind of organisms in the soil, and changes in these might well affect crop growth. That they do is obvious enough when the prevalent ones are parasitic on crops, but it is more difficult to get conclusive evidence about effects of some that are widely thought to be beneficial. Soils rich in organic matter are usually fertile soils; they also usually have high populations of organisms, including earthworms, but this does not prove that fertility depends on or is even influenced by earthworms. Such correlations may reflect cause and effect, but they are often fortuitous; organic soils could be fertile simply because they are richly endowed with plant nutrients, and the reason they contain many earthworms could be simply that the worms feed on organic matter. To get conclusive evidence is difficult, but our tests after five years on poor hill pasture still fail to show any benefits attributable to soil fauna, whereas plots treated with lime and mineral fertilisers have greatly improved during this time. However, in other conditions earthworms may affect the growth of crops, and a lack of earthworms sometimes has striking effects on unploughed soil. An apple orchard at Wisbech where copper fungicides have long been used now has few earthworms; the fallen leaves no longer get buried, and the soil is covered with a thick mat of partially decomposed leaves.

Bacterial fertilisers

Can the micro-flora of the soil be manipulated and offer better chances than the fauna of benefiting agricultural crops? To be fertile, soils must contain nitrifying bacteria, but these usually reflect the amount of nitrogen in the soil and only change its form, without adding anything to the total supply of nutrients. Can the nitrogen-fixers be usefully encouraged? Or any types of organism that may make available to plants nutrients that otherwise would remain unavailable? In Russia it seems to be accepted that this can be done by the simple process of inoculating seeds with bacterial cultures, mainly of *Azotobacter*. Many acres there are sown annually with seed treated with " bacterial fertilisers ", but few results have been published that allow the value of the treatment to be assessed critically. The preliminary experiments we report do not and could not show whether seed inoculation is of practical value, but the results are both interesting and puzzling. They show clearly that seed inoculation can produce exceedingly high populations of *Azotobacter* along the root system (rhizosphere) of plants, even though the soils in which the seeds were sown already contain the organism: for example, spring wheat from inoculated seed growing in peat soil had an average of 2,600 *Azotobacter* per gram of

rhizosphere soil, whereas rhizosphere soil from uninoculated plants had only 227 and soil away from roots 171. Yields in the field experiments, however, were little influenced by the greatly different population of *Azotobacter*. In contrast, inoculation with *Azotobacter* sometimes greatly increased the growth of various kinds of plants grown in pots, but responses were unpredictable, and as often as not inoculation did not significantly affect plant growth. Failure to affect plant growth did not depend on failure of the *Azotobacter* to become established, and large populations developed in the rhizosphere of plants whose growth did not differ from that of uninoculated plants. Nor did the response depend on the amount of nitrogen in the soil; sometimes inoculation with *Azotobacter* increased yields more and sometimes less when the nitrogen content was increased. There seems no question that inoculation can stimulate plant growth, but it does so only in certain conditions, which are as yet wholly undefined and will need specifying in detail before the value of inoculation can be predicted.

Queen substance and other biologically active materials

One phase of work on " queen substance ", done in collaboration with Dr. A. K. Callow of the National Institute for Medical Research, ended successfully by establishing its identity as 9-oxodec-2-enoic acid; the analysis was confirmed by synthesising the acid and showing the synthetic product to be as active as the natural one in inhibiting ovary development in worker bees and in preventing workers from rearing new queens. Now that " queen substance " can be produced in quantity, its practical use in bee-keeping can be fully tested. Tests with the synthesised acid show that it does not attract worker bees from a distance, as a queen bee does; a second substance with this attractive power has now been extracted from queens in ethanol, and its identity is being studied. It presumably ensures that workers will visit the queen and get the queen substance that controls their behaviour.

Another successful analysis and synthesis identified all four insecticidal constituents of pyrethrum extracts as 2: 4-dinitrophenylhydrazones, so bringing cinerins I and II into line with pyrethrins I and II. The insecticidal activities of all four can be enhanced by using them with some other substances (synergists) that alone are not insecticidal; it is of some interest that the relative activities of the individual pyrethrins and cinerins differ considerably depending on whether they are used with or without a synergist.

Progress was also made towards establishing the identity of another biologically active substance, namely, the " hatching factor " that is produced by roots of potato and tomato plants and stimulates eggs of potato-root eelworm to hatch; its constitution has still to be established, but it seems to be a monobasic acid, possibly with the gross constitution represented by the formula $C_{11}H_{16}O_4$. It does not contain the lactone ring suggested by other workers. Material with similar general properties to the potato-root eelworm hatching factor, but which specifically stimulates the hatching of beet eelworm, was isolated from diffusates produced by roots of rape seedlings.

Virus research

We reported last year that the virus-free stock of King Edward VII potatoes, produced by propagation from a plant obtained by culturing on agar the excised growing point from a stem, showed promise of being more vigorous than commercial stocks, all of which are infected. The results of the first field trials, made by the National Institute of Agricultural Botany, confirmed this promise by showing that, on average, the virus-free clone yielded 10% more weight of tubers than seven of the best obtainable stocks now being grown. There is now enough of the virus-free stock to supply some to potato-seed growers, but new results with the virus show that the stock will need checking to ensure that it remains virus-free. For the more than 30 years during which paracrinkle virus had been known to be in the King Edward variety, no insect had been found to transmit it and if the virus originally had an insect vector, it seemed to have lost it. This may be true of the virus strains contained in some stocks, but it is not true of all, for those in some commercial stocks tested this year were readily transmitted by the peach-potato aphis, *Myzus persicae*. If the virus-free stock is planted near such commercial ones, there is the obvious risk that it will become infected and lose its extra cropping power.

Further work with the Rothamsted culture of tobacco necrosis virus has explained many of the puzzling features of past results with this culture and revealed a new phenomenon, that one virus may depend wholly on another for its ability to multiply. For some years we have known that extracts from infected plants always contained specific nucleoprotein particles of two sizes, and sometimes of three, but the relationships between these particles was obscure. The smallest could be crystallised, but when taken to this state preparations had little infectivity compared with that of unfractionated leaf extracts. It seemed likely that the smallest particles either lost infectivity while being separated or were non-infective material produced as a side effect when the larger ones multiply, as does happen in infections with some other viruses. However, new methods of separating the particles of different sizes have brought a different conclusion. Neither the largest nor the smallest particles are infective, and the largest consist simply of twelve of the smallest aggregated in a specific manner; plants inoculated with them show no lesions, and no virus can later be detected in them. Plants inoculated with the middle-sized particles developed lesions, and extracts from them contain only middle-sized particles. Plants inoculated with these particles plus the smallest also develop lesions, though rather different in type, and extracts from these plants also contain particles of both sizes, in proportions roughly reflecting their relative amounts in the initial inoculum. The two particles seem to be unrelated viruses, but the small ones lack some function essential to their multiplication, and this lack is made good in cells where the large ones are multiplying. This phenomenon is still known only with the Rothamsted culture of tobacco necrosis virus, which may be unique, but if it applies to some others it might go far to explain some previously inexplicable outbreaks of virus diseases.

Much other new information, not only about the behaviour and structure of viruses but also about very many other subjects unmentioned in my inadequate survey, can be found in the succeeding pages. One review of the Report for 1959 stated that it contained little of immediate practical value to sugar-cane growers. This is probably equally true of the 1960 Report, but growers of many other crops will find something of practical value, and even some sugar-cane growers may find something of interest.

PHYSICS DEPARTMENT

H. L. Penman

Dr. R. K. Schofield died on 8 June 1960. He joined the department 32 years ago, was head of it from 1946 to 1954, and then spent two years as head of the Chemistry Department before taking up a Readership in Oxford.

D. Rijks completed his training period in January and is now working in Uganda. Dr. K. Yabuki, University of Osaka, Japan, came in August to work on agricultural meteorology; Dr. G. Contreras, a Ramsay Memorial Fellow from Madrid, came in December to work on soil water.

W. C. Game was awarded a B.E.M. in the New Year Honours List (1961), an event giving great pleasure to all who know of his 50 years of faithful service to the Station, particularly as meteorological observer.

Agricultural Meteorology

Woburn Irrigation Experiment, 1951–59

The third three-year cycle was completed in 1959, and it is expected that a synoptic review of the nine years' data will be published in 1961. The experiment has been doubly useful. First, as an exercise in agronomy, it has shown how farm crops respond to irrigation, and this is the aspect to be outlined here. Second, of equal interest and possibly of greater importance, it has provided raw material for studying dependence of growth on weather, but this aspect will be ignored now because it would need a long introduction and many line diagrams.

The ever-increasing number of farmers who use irrigation have a guide to management in a technical bulletin, published by the Ministry of Agriculture and based on earlier Rothamsted work (*The Calculation of Irrigation Need* ed. R. T. Pearl. London, H.M.S.O., 1954). It may be helpful to link the Woburn experiment with the bulletin, which gives estimates, based on weather data, of average monthly potential transpiration (April to September) for subcounties in England and Wales, and compares the six-month totals with the corresponding summer rainfall for the same areas. Making the arbitrary decision that a summer is one of "irrigation need" when the estimated transpiration exceeds the rainfall by more than 3 inches, the predicted frequency of need at Woburn is near seven years in ten and even greater to the south and east. This is a purely meteorological assessment, based on a guess at a plant factor which is unlikely to be true for all species, even if true for one; it makes no pretence at predicting how any kind of crop will respond if part or all of the rainfall deficiency is made good by irrigation. "Does irrigation work?" can only be answered in the field, and the Woburn experiment was designed to get relevant information on farm crops, watered at times and in amounts

determined by weekly estimates of potential transpiration calculated from weather data collected on the site of the experiment.

Of the nine summers, five satisfied the meteorological specification of "irrigation need", somewhat fewer than expected, partly for local reasons peculiar to the site, and partly because of the natural variability of weather. Growing four crops per year, twenty were taken off in the five drier years, and of these only two did not respond to irrigation. Of the sixteen crops grown in the wetter years only four responded positively to irrigation, and a few responded negatively when, after early irrigation, there was enough summer rain to cause leaching. Broadly, the meteorological forecast of irrigation need has proved to be a good general farming forecast, but, as succeeding paragraphs show, some qualification of the general statement is needed for each crop.

The experimental area is in four main sections, each with twelve plots permitting three-fold replication of four treatments. Series IV carried a ley throughout, first, 1951–53, as a grass/clover mixture (main components, S26 Cocksfoot and S100 White Clover), and then, 1954–59, as a pure grass stand (S37 Cocksfoot). On Series I to III there were three three-course rotations: 1951–53 early potatoes (Ulster Chieftain), sugar beet (Klein E), barley (Plumage Archer); 1954–56, main crop potatoes (Majestic), sugar beet, barley (Herta); 1957–59, spring beans (Spring Tick), sugar beet, spring wheat (Peko). Each crop got the basal fertiliser dressing thought best for it, with one variant (usually an extra nitrogen dressing) on half plots. Most of the watering was in doses of 0·5 inch, the four treatments always including unwatered control plots (O treatment) and plots kept near capacity (C treatment). Intermediate treatments (A and B) varied greatly, and sometimes were sacrificed to permit another fertiliser variant or a management treatment. The leys were cut at three- or four-week intervals throughout each summer—as though the crop were being managed for grass drying.

There is no common pattern in the summary tables that follow, because the points of interest vary from crop to crop. Most of them give total yields over several years, with details and decimals suppressed except where they may be helpful. Irrigation, *I*, is expressed in inches, and growth in the normal field unit, usually cwt. or tons/acre.

TABLE 1

Leys, 1951–59

N_3 treatment

Total growth, *G*, in cwt. dry matter per acre

Treatment		O	A		B		C		Mean
		G	*G*	*I*	*G*	*I*	*G*	*I*	
1951–53 (3 years)	Grass	175	193	—	203	—	205	—	—
	Clover	24	29	—	41	—	50	—	—
	Whole crop	199	222	5·4	244	8·6	255	14·2	—
Response/inch	Grass	—	3·3	—	3·2	—	2·1	—	2·7
	Clover	—	0·9	—	2·0	—	1·8	—	1·7
	Whole	—	4·2	—	5·2	—	3·9	—	4·4
1954–59 (6 years)	Grass	353	388	9·5	411	21·4	444	31·0	—
Response/inch		—	2·7	—	2·7	—	2·9	—	2·8

Results are given for the N_2 treatment only, as no other was consistently applied throughout the 9 years. For the first 6 years there was N_1 at half the N_2 rate: for the last three, there was N_4 at twice the N_2 rate. The nitrogen was applied in spring and after every cut except the last, with $N_2 = 0{\cdot}3$ cwt. N per acre. The number of cuts varied up to eight per summer, and the average total summer application can be taken as close to 2·0 cwt. N per acre.

Both grass and clover responded to irrigation, the clover proportionately more than the grass even at this rate of nitrogen fertilisation. At the lower rate (N_1) the proportion of clover in the irrigated sward was greater than at N_2. The mean annual growth and response of the grass to irrigation were about the same in the two periods. In the later period, when nitrogen dressings were compared in the ratios 1 : 2 : 4, the corresponding growth rate ratios for the fully irrigated plots (C treatment) were 1 : 1·25 : 1·60, while for the control plots the spread was smaller. In *effect*, doubling the nitrogen dressing behaves as though it adds 0·5 inches to soil water reserves. To maintain maximum growth, the soil must be kept near field capacity (the tolerable moisture deficits being 1·0, 1·5 and 2·0 inches for treatments N_1, N_2 and N_4 respectively), and it is because of this that the response per inch (bottom line of table) is constant. These responses would be increased by 50 per cent were the data used restricted to those occasions when subsequent rain did not render irrigation superfluous. Within the period very good responses to irrigation were obtained in 1951, 1952, 1955, 1957 and 1959; good responses in 1953 and 1956; and zero responses in 1954 and 1958.

TABLE 2

Sugar beet, 1951–59

Total growth per acre (9 years)

	O		Best treatment (Total I = 22 inches)	
	N_1	N_2	N_1	N_2
Clean beet, tons	130	146	146	162
Tops, tons	82	108	93	122
Sugar, cwt.	470	521	527	582
Response/inch, sugar	—	—	2·6	2·8
Sugar %, mean	18·0	17·8	17·9	17·7

This is the most difficult crop of all. Whereas with grass attention need be paid only to the leaves, and with potatoes to the tubers, with sugar beet attention must be paid to tops, roots and sugar content, all of which may react differently to watering and fertiliser treatment. In addition, year-to-year fluctuations in virus disease produce much bigger changes in yield than does management.

The nitrogen dressings were $N_1 = 0{\cdot}4$, $N_2 = 0{\cdot}8$ cwt. N per acre for the first 6 years, increased to 0·6 and 1·2 cwt./acre for the last three. The scatter in the yields was such that the change was not detectable, and there is no separation in the table. In the belief that better management of sugar-beet irrigation can be achieved, the table is selective and gives the total yields for the treatments that

gave the best yield of sugar each year: in five of the years this was not the treatment that got the most irrigation. A deficit of 2 inches at six weeks after singling seems to be tolerated without any major effect on yield (and may, in fact, be desirable to encourage root extension), which is in accord with known good commercial irrigation practice. Out of 30 × 2 sub-treatments harvested in the 9 years only four at N_1 level, and two at N_2 level, gave less than 80% of the yield of the best treatment in that particular season. Other broad conclusions are perhaps best considered as guides to further inquiry: The most consistent response to extra nitrogen is in the yield of tops, and it is greatest after winters of greatest leaching, and hence dependent on the irrigation treatments of the previous year. The growth of the tops seems to depend on watering treatment from the time of sowing onward, that of the roots on watering treatment from time of singling onward, and the sugar content (%) is almost independent of watering treatment or nitrogen treatment, but increases with the amount of sunshine in the four months after singling. As the table shows, the response of the crop to water is independent of nitrogen treatment, and on average—but only as an average—it is about the same as the response to doubling of the nitrogen dressing, at about 11%. Within the nine years very good responses to water were obtained in 1952, 1955 and 1959, an average response in 1957, and zero, or slightly negative responses in 1953, 1954, 1956, 1957 and 1958.

TABLE 3

Potatoes, 1951–56

Total yield of tubers (tons/acre)

	O		(*a*)			(*b*)			C		
Earlies	N_1	N_2	N_1	N_2	*I*	N_1	N_2	*I*	N_1	N_2	*I*
1951–53 (3 years)	20	22	22	26	2·1	26	29	4·6	29	34	6·9
Response/inch	—	—	1·1	1·7	—	1·3	1·5	—	1·4	1·8	—
Maincrop											
1954–56 (3 years)	39	45	44	50	2·4	45	51	6·6	47	55	9·0
Response/inch	—	—	2·0	2·2	—	0·9	1·0	—	0·9	1·1	—

The " early " potatoes were harvested about mid-July, and the haulms of the main crop killed in September. Two levels of nitrogen were $N_1 = 0{\cdot}5$, $N_2 = 1{\cdot}0$ cwt. N per acre, the basal PK was the same in both rotations, and the main crop potatoes also got 15 tons of dung per acre. One of the extraordinary results of the detailed analysis—probably fortuitous—is that in spite of this major difference in manuring the two sets of data can be fitted by a common growth curve.

Potatoes respond well to irrigation, and, like grass, grow best when the soil water content is kept close to field capacity, a major check to growth occurring whenever the deficit exceeds 1·0 inch. For the table, the irrigation treatments were arranged in ascending order of magnitude, but they are all included. The early crop responded better to irrigation at the higher nitrogen dressing, whereas the main-crop response was almost independent of nitrogen dressing. Irrigation prolonged the period of leaf development, and delayed flowering and death of tops. Within the six years very good

responses were obtained in 1951, 1952 and 1955, a good response in 1953, and no response in 1954 and 1956.

The primary reason for including cereals was to make the rotations realistic. The nitrogen treatments for the barley were $N_1 = 0{\cdot}2$, $N_2 = 0{\cdot}4$ cwt. N per acre, and for the wheat were $N_1 = 0{\cdot}4$, $N_2 = 0{\cdot}8$ cwt. N per acre. Because of the change in variety

TABLE 4

Spring cereals, 1951–59

Total yield of grain (cwt./acre)

	O		Best treatment		
Barley	N_1	N_2	N_1	N_2	I
1951–53 (3 years)	67	83	75	90	6·1
1954–56 (3 years)	88	108	96	114	3·4
Total	155	192	172	204	9·5
Response/inch	—	—	1·8	1·3	—
Wheat					
1957–59 (3 years)	68	70	81	91	7·9
Response/inch	—	—	1·7	2·6	—

in 1954, the barley yields are given separately for each rotation, and, again acting on the presumption that better knowledge will circumvent waste of water, the best yielding treatments have been chosen to show what irrigation can achieve. It is clear that extra nitrogen is much more effective than irrigation in increasing barley yields, and the lower the nitrogen level, the greater the response to irrigation. Wheat, in clear contrast, seems to need the water before it can respond to extra nitrogen. Good responses were obtained in 1951, 1956, 1957 and 1959, about average in 1952, and zero or negative responses in 1953, 1954, 1955 and 1958.

TABLE 5

Spring beans, 1957–59

Annual yield of grain (cwt./acre)

	O		C		
	D_0	D_1	D_0	D_1	I
1957	11·8	14·0	25·6	25·7	4·0
1958	15·3	14·4	16·0	14·8	1·0
1959	8·2	9·0	21·0	21·0	4·5
Total	35	37	63	62	9·5
Response/inch	—	—	2·8	2·5	—

The basal manuring was PK (*no* nitrogen) with dung as variant ($D_1 = 12$ tons/acre). Spraying against aphids was included as a treatment in 1957 and 1959, and though there were minor interactions of irrigation, dung and spraying treatments in the dry summer of 1959, they are ignored in the table. There is no doubt that beans respond to irrigation in a dry summer, and in 1959 the plants grew well over 6 feet tall, over-topping the spray lines for a while. With this great inter-node expansion there was maintained vegetative growth and delayed ripening. The crop responded positively to dung only when water supply was limiting growth, and the response was zero or negative when the soil was kept moist, either by irrigation in 1957 and 1959 or by rain in 1958.

As already stated, the test at Woburn suggests that the " Frequency of Need " map in the technical bulletin is a good guide to general farming need for summer irrigation. For grass and potatoes it underestimates the frequency, for beans it may be about correct, for sugar beet and cereals it is probably an overestimate. Whereas the first three crops seem to need water at all stages of growth, the chief threat to sugar beet lies in a dry late summer, and that to cereals in a dry early summer. Not all of the unnecessary irrigation in the nine years was caused by the legitimate conditions of an experiment: much of it was unavoidable, and this type of waste will continue in experiments and in farming practice until weather can be forecast for the next week or two. It is reassuring to know that development of such medium-range forecasts is an important part of the research programme of the Meteorological Office.

Woburn irrigation experiment, 1960

Until the first week of June the equipment was in use every week: thereafter it was idle. All crops responded. *Grass:* Nearly all the response was in the first three cuts (up to late June). *Barley:* Again, a small increase in nitrogen dressing was more efficient than extra water. *Winter beans:* The unwatered yield was as good as the best previously obtained with irrigated spring beans: the effect of irrigation was surprisingly great. *Early potatoes:* The results are for plots given normal cultivations. Six of the twelve plots had minimum cultivation and a " Simazine " spray a week after planting. All yields from these plots were smaller than those in the table, by 1·9 tons/acre, unwatered, and by 2·4 tons/acre, irrigated. (Penman and Barnes.)

TABLE 6

Woburn Irrigation, 1960

Crop	Period	Rain (inches)	Irrigation (inches)	Plot	Yield	
Grass	25 Apr.–3 Oct.	14·8	—	ON_2	84	Dry matter, cwt./acre, 8 cuts
				ON_4	93	
		14·8	3·8	CN_2	95	
				CN_4	109	
Barley	25 Apr.–8 Aug.	8·3	—	ON_1	22	Grain, cwt./acre
				ON_2	30	
		8·3	2·0	CN_1	26	
				CN_2	33	
Winter beans	25 Apr.–8 Aug.	8·3	—	O	26	Grain, cwt./acre
		8·3	3·5	C	40	
Early potatoes	25 Apr.–11 July	6·1	—	ON_1	9·1	Tubers, tons/acre
				ON_2	10·4	
		6·1	2·2	CN_1	10·9	
				CN_2	13·0	

Micro-meteorology

Measurements of temperature, humidity and wind profiles over grass, started in spring 1959, were maintained throughout the winter (for the first time) and are still in progress. Processing of the data proceeds slowly, and analysis will be a formidable task. During

hay-making on the site in June and August rates of drying were measured by sampling, and these will be compared with estimates from profile measurements taken at the same time. Most of the water (about $\frac{3}{4}$) evaporated during the first full (sunny) day of drying, and on the clear night after it about $\frac{1}{4}$ of this returned as dew. On subsequent nights about half of the daytime evaporation returned as dew.

Improvements in instrumentation continue, the main effort being for wind measurements in crops, wind direction, ventilation of psychrometers and a better form of output for the neutron-scattering equipment used in soil-water measurements. (Long.)

Radiation balance

The amount of energy used in evaporating water from a closed crop canopy is only slightly less than the *net* radiation received by the canopy. The hour-by-hour changes in assimilation of atmospheric carbon dioxide are strongly correlated with *solar* radiation. Knowledge of the relation between net radiation and solar radiation would therefore seem to be fundamental to any study of the relation between transpiration and growth, and could be relevant to agriculture outside the temperate zone in which the knowledge is being sought. Rothamsted records for cloudless daylight hours show a linear relation between net radiation and solar radiation, which can be interpreted in terms of a heating coefficient that allows for changes in long-wave loss with changes in surface temperature (1·7). Measurements with a Linke–Feussner radiometer (kindly lent by Prof. P. A. Sheppard, Imperial College) confirmed that both surface temperature and long-wave radiation exchange are linearly related to net radiation when the sky is clear. Similar work remains to be done for cloudy hours, but as an intermediate step an empirical formula has been devised to give a value of long-wave exchange in terms of screen vapour pressure, screen temperature and cloudiness (1·6). When applied to sites that have records of short-wave radiation, the formula suggests that there is little variation in mean annual values of net radiation between northern Scotland and southern England. There is here some conflict with estimates of annual evaporation for the same sites, and both sets of estimates need further probing.

Water balance

In the fourth year of use of the field balance the crop was grass, sown in spring 1959. The early 1959 records, examined to get measures of evaporation from bare soil, show, as expected, that after heavy rain the ratio of evaporation from the soil (E_s) to that from an open water tank of about the same size (E_o) is close to unity. When the deficit reached only 5 mm. E_s/E_o decreased to 0·4, an unexpectedly low value. The ratio increased on days after dew nights that added 0·3–0·4 mm. of water to the soil. Laboratory experiments are planned, to link these field observations with previous work of Penman and current work of Rose on vapour transfer.

A second field balance was acquired, and simultaneous measurements of evaporation from two crops will start in 1961.

Carbon dioxide balance

Further analysis of the 1958 data for sugar beet yielded estimates of the diffusion resistances governing uptake of carbon dioxide and discharge of water vapour. The dependence of gross assimilation on radiation intensity for this field crop accords closely with that found by Dr. P. Gaastra in Holland, working on single leaves in a laboratory.

In 1960 carbon dioxide gradients were measured over grass, and fluxes calculated from wind records taken by Long. At the end of May the midday peak of gross assimilation rate reached 0·6 mg. $cm.^{-2}$ $hr.^{-1}$, while the crop height was increasing by 2·5 cm./day. After cutting in June growth was slower, and the peak assimilation rate was only 0·4 mg. $cm.^{-2}$ $hr.^{-1}$, equal to the rate calculated for sugar beet in August 1958. With new equipment, installed in late summer, concentration differences are now measured over five steps from soil surface up to 1 m. above. Daytime records show that carbon dioxide moves into the crop canopy from the soil and from the atmosphere, and two methods of direct measurement of the flux from the soil are being tried. Progress is good, and there are hopes of getting hourly values in addition to the daily totals now being measured.

Radiometry

The small portable solarimeter, working into an electrolytic integrator, gives daily totals of radiation at Rothamsted agreeing well with those from the standard Kipp instrument. Between January and July the standard deviation in weekly totals was only 40 cal. $cm.^{-2}$. A similar unit was installed at Woburn in June, and since then there has been very little difference in weekly totals of radiation at the two stations. Six units, set up in a crop of oats, showed important diurnal changes in the distribution of radiation with height; two others, modified to accept only visible radiation (0·4–0·7 μ), were used to measure light distribution in a crop during an experiment by the Botany Department (see p. 97).

Two simple types of net radiometer were made, one of which requires no ventilation. A general account of these, and other radiation instruments devised over the past few years, is in preparation. (Monteith, Szeicz and Yabuki.)

Soil Physics

Electrical charges on clays

Clays are unstable if they are first given an acid treatment and then washed with distilled water, because the positive charges on the edges of the clay particles produce electrical stresses that are too great for the strength of the structure. Exchangeable aluminium is always present after such treatment. It has now been proved that the newly exposed edges of the clay particles are uncharged. Decomposition may be caused by direct acid attack, and experiments are in progress attempting to distinguish between the two types of breakdown.

Phases in the uptake of cetyl trimethyl ammonium bromide

(CTAB) by clays can be detected from conductivity measurements. The CTAB itself has a critical concentration in solution at which it forms micelles, and in clay suspensions this critical concentration is not reached until CTAB cations and ion pairs have been adsorbed in amount equivalent to nearly three times the cation-exchange capacity of the clay. Assuming the CTAB molecule has an area of cross-section of 41 $Å^2$, estimates of the surface areas of clays are 200 $m.^2 g.^{-1}$ for an illite, and 500 $m.^2g.^{-1}$ for a bentonite, the latter being smaller than the theoretical figure of 800 $m.^2g.^{-1}$. The discrepancy may be accounted for by incomplete dispersion of the bentonite. For Peerless kaolin the area estimated in this way is of the same order as that found by measuring low-temperature gas adsorption (17 $m.^2g.^{-1}$). (Cashen.)

Soil structure

Plots ploughed after 4 years under ley or fallow were planted with spring beans. Given the same cultivation, the amount needed to get a tilth after grass was too much for the former fallow plots, and these puddled badly, so that differences in growth of the beans must be attributed partly, at least, to conditions imposed by cultivation rather than wholly to pre-treatment. From germination to harvest the plants on the puddled plots were inferior, with restricted root development and poorer nodulation. Although the structural units of all plots had the same porosity, the aggregates after the leys were much more stable to wetting than those after fallow, and formed a less rigid root-bed while the soil was dry. This double improvement in root environment was achieved without very much of the residual organic matter from the grass being intimately incorporated within the soil crumbs.

Soil aeration

Having completed the work on diffusion in dry porous materials, the effects of a liquid phase in the system are now being measured (1.4). When there is no swelling a clear general picture emerges: at the water content that just saturates the soil aggregates, the aggregates behave like " dry " solid particles of the same shape. As more water is added and the inter-crumb space is filled, the diffusion constant of the system decreases, being proportional to the fourth power of the remaining air-filled pore-space. A change of water content in the opposite direction gives results that depend on the origin and previous history of the crumbs: as the crumbs are dried, the diffusion coefficient increases because extra channels are opened, but the increase is small, and in no soil so far examined has the maximum increase per unit of crumb pore-space (at complete dryness) been as great as the value per unit of inter-crumb pore-space at crumb saturation. Macro-aeration of soil in the field must depend almost entirely on the inter-crumb pore-space, and between water-logging and field capacity it will be subject to the fourth-power law, and will not be significantly increased when a soil moisture deficit is established by transpiration. Further study of the micro-aeration of the crumbs offers great possibilities, ranging from an empirical specification of a " structure " factor to an

understanding of the physics of gas exchange near the surfaces of roots and other biotic components of the soil.

When swelling occurs in a confined sample the inter-crumb pore-space is decreased. The change is not completely reversible on drying, and the degree of hysteresis depends on the strength of the crumbs when wet. (Currie.)

Soil water

Measurement of water-vapour movement in unsaturated media continued, using building stones and sieved field soils as test materials. The presence of liquid in the system increased the transfer rate above that calculated for pure vapour diffusion. In parallel there was a complete series of measurements of the diffusion of hydrogen through the same materials (Currie technique), and from the two sets of data it should be possible to sort out the interactions of movement as liquid and movement as vapour. As a welcome by-product, the experimental technique provides a quick and reproducible way of measuring water potentials in the range pF 2·5–5·6.

The transfer rate per unit *total* potential gradient is less when dissolved salts are present than when they are not. The magnitude of the decrease can be calculated provided the salt concentration and ionic diffusion coefficient are known. Measurements confirm the dependence on concentration, and lead to estimates of ionic diffusion coefficients in saturated building stones that are concordant with gaseous diffusion through the same stones when dry. (Rose.)

CHEMISTRY DEPARTMENT

G. W. Cooke

I. K. Otter left in March and R. K. Cunningham joined the staff in June. P. W. Arnold and D. S. Jenkinson attended the Seventh Congress of the International Society of Soil Science at Madison, Wisconsin. G. W. Cooke visited Israel in March as a guest of Dead Sea Works Ltd. and of the Agricultural Research Station of the Israel Ministry of Agriculture; he gave a series of lectures and visited research institutes and experimental farms. In October Cooke attended a Conference at Seville on " Nitrogen in Agriculture " organised by the journal *Agrochimica*.

R. G. Heathcote of the Colonial Research Service left in September to go to Nigeria. Y. C. Lin (from Hong Kong) joined the Department for training in soil-fertility work. N. J. Barrow (Australia), M. Birecki (Poland), S. Oliver (Spain), R. C. Salmon (Rhodesia), K. Singh (India), L. V. Vaidyanathan (India) and Y. Yamada (Japan) all worked in the Department during the year.

Soil Organic Matter and Organic Manures

Soil organic matter and freshly added organic materials have quite different effects on crops. Decomposed organic matter in soil contains reserves of plant nutrients (mainly N, P and S) that are released slowly; it also modifies permanently some of the physico-chemical properties of soil, but often it has relatively little effect on gross physical characters. Freshly added plant residues and organic manures usually improve physical properties and also provide a " flush " of N and P when they decompose; both effects may increase crop yields but are short-lived. In laboratory work we are attempting to distinguish between " old " and " new " organic matter and to measure rates of decay. In field experiments we are examining the effects of farmyard manure, and of crop residues to try to separate nutrient and physical actions. We are also developing simple methods for measuring physical improvements in soils produced by organic matter, and for characterising " difficult " soils where crops benefit from improving physical properties. Such work is essential for interpreting experiments on organic manures and for assessing practices that increase soil organic matter.

Decomposition of plant material in soil

Ryegrass roots and tops uniformly labelled with ^{14}C were incubated with soil from two Broadbalk plots (Plot 2B has farmyard manure (FYM) each year and the soil has 2·4% of organic C, Plot 3 has no manure or fertiliser and the soil has only 0·97% of organic C). With both soils the plant carbon lost as CO_2 was directly proportional to the amount added when N supply was enough for microbial activity. About one-third of the plant carbon

(from either roots or tops) was left in the soil after laboratory incubations lasting 156 days, and after field incubations lasting from April to October; there was little further loss of carbon in the field during the next winter. Adding fresh ryegrass tops increased rates of decomposition of "native" soil organic matter, in soil from Plot 2B by 50% and in soil from Plot 3 by 100%. Some of the CO_2 evolved during incubation was fixed (presumably by micro-organisms) and returned to the soil organic matter. The same proportion of CO_2 was fixed in the laboratory experiments on both soils ($1\frac{1}{2}$% of that evolved), and was not affected by adding plant material. (Jenkinson.)

After ryegrass uniformly labelled with ^{14}C had decomposed in soil for a year in the field, residual activity (31% of that added) was determined in fractions of soil organic matter separated by J. M. Bremner and T. Harada's system (*J. agric. Sci.* (1959), **52**, 137). The results given are from an experiment where 0·3% of labelled plant material was added to soil from Broadbalk Plot 2B:

	Total carbon	Added plant carbon
	(Percentages of carbon in each fraction)	
Inorganic	5	1
Soluble in 0·1*N*-HCl	1	4
Soluble in 0·5*N*-NaOH	48	60
Soluble in *N*-HCl : *N*-HF	4	4
Residual	41	32

The distribution of added plant carbon was not very different from that of carbon in the whole soil organic matter. "New" soil organic matter did not occur predominantly in one fraction of the whole organic matter, as would happen if this method separated "labile" and "stable" fractions of organic carbon in soils. The distribution of "new" organic matter in the two Broadbalk soils was similar. (Jenkinson.)

Oxidation of soil organic matter by dichromate

In titrimetric methods for determining carbon in soil, the oxidising mixtures must be at a high temperature to oxidise organic matter completely, but this also tends to decompose the dichromate. By omitting H_2SO_4 and using only H_3PO_4 and $K_2Cr_2O_7$ in the mixture, oxidation may be done at 175° without decomposing dichromate rapidly. The organic carbon of a number of soils was oxidised quantitatively by this method, the CO_2 being collected gravimetrically and the O_2 used determined titrimetrically on the same sample.

$$\text{The ratio } \frac{\%\text{ C calculated from } O_2 \text{ used}}{\%\text{ C calculated from } CO_2 \text{ evolved}}$$

ranges from 2 for CH_4 to 0 for CO_2, with soils about 1. Soils differed significantly in this ratio: values for Broadbalk FYM-treated plot (2B) and the unmanured plot (3) were 1·05 and 0·97 respectively, implying that carbon in the FYM plot is less oxidised. The oxidation ratio of a low-moor-alkaline peat was 1·00, that of a high-moor sedge peat 1·16. For this ratio to be determined accurately, samples must contain no Fe^{++}, Cl^- or charcoal. (Jenkinson.)

Farmyard manure

Elaborate field experiments are needed to measure the separate contributions towards crop yields made by the nutrients in FYM and by any other direct or indirect effects it may have. Besides N, P and K, other elements supplied, such as Ca, Mg and Na, may increase yields. Neither the chemical forms of these elements in manure, nor their availabilities to plants, are known precisely, which complicates even further any experiment on FYM that attempts to interpret its value.

Chemical composition. The total contents of N, P and K differ in different samples of farmyard manure, depending on origin and on storage methods. Three samples used in experiments at Rothamsted and Woburn had the following contents:

	Dry matter	Total		
		N	P	K
Sample	(%)	(% in dry matter)		
1	20·0	2·0	0·3	1·5
2	18·0	3·0	0·7	2·0
3	25·5	3·5	1·2	4·4

The differences illustrate the difficulties of comparing similar amounts of nutrients as FYM and as fertilisers in field experiments of simple design. Thus if FYM at 15 tons/acre were compared with 0·9 cwt. N, 0·75 cwt. P_2O_5 and 1·5 cwt. K_2O/acre; the comparisons that were satisfactory with either sample 1 or 2 might fail with sample 3 (this was so high in K that 15 tons/acre supplied 4 cwt. K_2O/acre in a readily soluble form).

The solubilities of Ca, Mg, K and Na of FYM in several solvents were determined for a few samples (Smith). Amounts of elements dissolved in boiling concentrated HCl were used as " total " contents, and the average values for the manures tested were Ca 1·7%, Mg 0·4%, K 3·6% and Na 0·3%. Of these amounts water dissolved 5% of Ca, 10% of Mg, 75% of K and 80% of Na. Cold *N*-HCl and *N*-ammonium acetate both dissolved 95% of the total K and 100% of the Na. In contrast, these two solvents extracted different proportions of Ca and Mg. Ammonium acetate extracted 15% more of the Ca and Mg than did water, and dilute HCl dissolved 85% of the Ca but only 40% of the Mg. Approximately all the K and Na in FYM can be rated as available to crops, but more than half of the Mg is not even soluble in dilute acid. Some at least of the Ca that is insoluble in a neutral salt solution is present as carbonate, which would serve as a Ca reserve.

Position effects. Rothamsted experiments summarised by H. D. Patterson and D. J. Watson (*Rep. Rothamst. exp. Sta.* for 1959, pp. 164–168) showed that FYM was more effective relative to fertilisers for sugar beet than for potatoes, perhaps because the N, P and K equivalents of FYM are greater for sugar beet than potatoes. Besides the possibility that nutrients in FYM and in fertilisers have not the same relative efficiencies for varied crops, the positions in the soil of the nutrients supplied by the two kinds of materials differ, especially where fertilisers are broadcast on the surface of a seedbed for crops like sugar beet. At sowing, and for at least

a month afterwards, nearly all broadcast P and K fertilisers are confined to the top 2 or 3 inches of soil, and dry weather after sowing prevents much of these nutrients reaching plant roots. In contrast, nutrients supplied by FYM are deeper and in moister soil.

Differences in both quantities and position of nutrients may explain the higher yields from FYM than from fertilisers obtained in both the Market-garden and the Ley–Arable Experiments at Woburn. In the Market-garden Experiment FYM supplied much more total N, P and K than were given as fertilisers, or were needed by the red beet grown. Both P and K have accumulated in the soil from FYM dressings, and analyses below show the two nutrients have moved into the subsoil at least 24 inches deep.

Readily-soluble P and K (mg./100 g. of soil)

Depth (in.)	Fertiliser plots		Farmyard manure plots	
	P	K	P	K
0–9	31	8	85	35
12–18	12	6	21	33
18–24	9	5	17	32

P and K levels are much higher in the FYM plots; the nearly constant high level of K for all three sampling depths in FYM plots indicates that much added K has passed below 24 inches and is now out of range of globe beet roots. The 30 tons/acre average annual dressings of FYM used are maintaining at each depth a " saturation value " of 30–35 mg. K/100 g. of soil. On the plots of the Rothamsted Classical Experiments " saturation " level has not been reached, even in the surface soil, for, although the readily soluble K is much higher on Barnfield than the " saturation value " at Woburn, K levels in Rothamsted subsoils (9–18 inches) are only two-thirds of those in surface soils.

In the Market-garden Experiment at Woburn much P has accumulated in soils where FYM and sewage sludge have been applied for the last 18 years. Table 1 shows the gains, relative to soil that has had P only as fertilisers.

Most of the gains in total P are as increases of inorganic P soluble in acetic acid and in NaOH; organic P increases are surprisingly small. Apart from the increase in alkali-soluble inorganic P in the second depth of the FYM plots, most of the P has accumulated in the 0–9-inch layer; but gains of P, expressed as percentages of the total gain for each profile (Table 1), show that much more inorganic P had moved into the second soil depth with FYM than with sludge, even though much more total P was applied as sludge than as FYM. The Market-garden Experiment has been redesigned to test higher rates of fertilisers incorporated at two depths, and magnesium. The results should indicate whether factors other than the nutrients in FYM improve the crops.

In the Woburn Ley–Arable Experiment from 1956 to 1959 FYM applied to sugar beet gave 10 cwt. more sugar/acre each year when this crop was grown after 3 years of arable cropping or 3 years of lucerne, whereas NK fertilisers had only small effects on yields. Where the test crop of beet was preceded by a 3-year grazed ley,

however, there was no response to manure, and yields without FYM were as good as in the other rotations where FYM was given.

Where no FYM was given the soil had little readily soluble K (3·5 mg. K/100 g. soil) after all rotations except the grazed ley, where it was high (7 mg. K). Where FYM was given to beet, soluble K values were high immediately after the crop was taken, but at the end of 3 years of arable cropping, or 3 years of lucerne, values (*ca* 4 mg. K) were only a little above those of plots receiving fertilisers only. Soil under grazed ley still had 10 mg. of soluble K/100 g. when the plots were due for the next dressing of FYM.

TABLE 1

Extra P in soils of the Woburn Market-garden Experiment receiving farmyard manure and sewage sludge, as compared with soils having fertilisers

	Farmyard manure plots				Sewage sludge plots			
		Soluble				Soluble		
Depth (in.)	Total	In acetic acid	In NaOH Inorganic	In NaOH Organic	Total	In acetic acid	In NaOH Inorganic	In NaOH Organic
	mg. of P per 100 g. soil							
0–9	45	34	9	7	145	79	36	18
12–18	25	8	19	3	10	3	5	1
18–24	15	4	10	2	10	3	2	0
	percentages of gains for the whole profile							
0–9	—	74	24	58	—	93	84	95
12–18	—	17	50	25	—	4	12	5
18–24	—	9	26	17	—	4	4	0

Soluble K in the soils of the arable rotations without FYM is low because more K is withdrawn by the crops than is added by fertilisers, but in the grazed ley rotation 0·7 cwt. K_2O/acre was gained in the 5-year rotation of test and treatment crops. Where FYM was applied, the K added exceeded the K withdrawn in all rotations; the accumulation was greatest with the grazed ley (3·6 cwt. K_2O/acre per rotation).

In this experiment the K fertiliser broadcast on the surface before sowing supplies 0·9 cwt. K_2O/acre; the 15 tons/acre dressing of FYM, which is ploughed in, supplies 3·9 cwt. K_2O/acre. The fertiliser K has had little effect on the yield or on K uptake by sugar beet; in contrast, both K accumulated in the soil during the grazing period and K supplied by FYM have greatly increased percentage K in beet tops:

Percentage K in dry matter of sugar-beet tops

	Without manure	Increase by Fertiliser	Increase by FYM
Arable rotation	2·2	0·2	1·1
Grazed ley rotation	3·6	0·05	0·6

The Market-garden and the Ley–Arable Experiments at Woburn both suggest that differences in the amounts of K supplied by

fertilisers and by FYM, and also differences in the positions of fertiliser-K and of K from FYM within the soil, may account for much of the greater yields produced by FYM than by fertilisers. A preliminary experiment tested these two factors in 1960 on Stackyard Field at Woburn on land that had grown sugar beet in 1959 and where the soluble soil K was higher than in the plots of the arable rotations of the Ley–Arable Experiment. The fertilisers were either broadcast on the seedbed or dug in and were compared with FYM (15 tons/acre) and with peat saturated with solutions of NH_4NO_3 and KCl at rates so adjusted that the test dressing provided as much organic matter as the FYM treatment, and as much N and K as the NK fertiliser treatment. The whole experimental site received the same basal dressing/acre as the Ley–Arable Experiment (0·7 cwt. N, 0·7 cwt. P_2O_5 and 0·9 cwt. K_2O). Table 2 gives weights of sugar-beet seedlings at singling and tops and roots at harvest. There were clear gains from using extra NK fertilisers and also from digging the dressings in. In the Market-garden Experiment FYM gave greater yields of red beet than fertilisers, and the beet developed earlier; in this experiment sugar-beet seedlings with NK fertilisers dug in were even earlier than those with FYM. At harvest FYM gave nearly 1·5 tons more roots per acre, but slightly less tops, than dug-in NK fertilisers; both treatments increased yields by about 50% above the "untreated" plots (which had received the standard dressings of the Ley–Arable Experiment).

TABLE 2

Weights of sugar beet at singling time and harvest

Treatment/acre (addition to basal NPK)		At singling (g. dry matter/ microplot)	At harvest (tons/acre) Tops	Roots
None		20	10·3	9·3
0·7 cwt. N	Broadcast	21	16·2	11·3
	Dug in	33	15·6	11·9
3·6 cwt. K_2O	Broadcast	11	10·7	9·7
	Dug in	24	11·2	12·9
0·7 cwt. N+ 3·6 cwt. K_2O	Broadcast	12	15·1	12·4
	Dug in	48	17·2	14·6
FYM		25	16·5	16·0
Enriched peat		38	16·1	15·3

Broadcast NK fertilisers checked germination and retarded growth of the seedlings; at harvest yields of tops and roots were each 2 tons/acre lower than from the same fertilisers dug in. Putting the K fertiliser lower in the soil increased its effectiveness, but much of the difference in yields of roots between fertilisers and FYM was eliminated by equalising the amounts of K applied. (Warren and Johnston.)

Organic matter and soil structure

On many soils, Rothamsted clay is an example, crops grown in continued arable systems yield well for many years without needing more organic materials to improve structure than the residues of crops grown on the land; with other soils, this treatment degrades

structure because organic matter is lost, and yields fall. At present there is no better basis for advising farmers on the need to improve soil structure than local knowledge, and there is no suitable routine laboratory or field procedure for identifying "difficult" soils. Poor structure that interferes with root growth is probably associated with proportions of sand and silt that lead to close packing of soil, and with too little clay or organic matter of the right kind to bind aggregates. Close packing leads to shortages of water and air, and to pores that are too small for roots to grow through when the soil mass dries and becomes rigid.

Clay and sandy soils, mainly from Rothamsted and Woburn, which have had contrasted but continuous treatments, were used in laboratory experiments. Thin sections made by D. A. Osmond (Soil Survey) showed close packing in natural aggregates of sandy soils under continuous arable cultivation. Pore-size measurements showed that checks to root growth were not likely in the clays, but were possible in the sands. The effects of grass grown for many years, and of regular annual dressings of FYM, on several physical properties were measured in both sands and clays. Continuous grass was much more effective than regular dressings of FYM in improving the soils by making them more permeable and giving them a structure stable to water and resistant to effects of mechanical ill-treatment. In both sands and clays, aggregates formed under permanent grass were quite stable to water, and the soils were very permeable. Annual dressings of FYM prevented the crumbs of clay soil slaking, but did little to stabilise the sand. Clay aggregates from land cultivated continuously without FYM slaked, but not as seriously as sands having the same treatment (these were quite unstable). Sandy soils in continuous arable cultivation had low water permeabilities after slaking, but where FYM had been given each year the slaked soils were more permeable. Clay soil continuously cultivated had low permeability after slaking, but where FYM had been applied each year slaking was prevented and permeability remained high.

A practical test was developed. The percentage loss in pore space, after wetting and draining an aggregated soil sample twice, measured *structural instability*; passing water through the sample remaining from the slaking test measured *permeability*. The two parts of this test indicate whether soil structure will deteriorate in wet weather and whether trouble may be expected from impermeability when slaking occurs. Samples from the Woburn Ley–Arable Experiment showed that continuous arable cultivation without FYM gave very unstable aggregates and the soil packed badly after slaking. Where FYM was given to root crops in the rotation, soil structure was a little more stable and permeability was higher, but neither improvement from FYM was great. Six months after undersowing cereals with a ley, the soil was much more stable, but it still packed badly. Three years under ley stabilised structure completely, but most of the improvement was lost a year after ploughing.

The test devised needs no elaborate apparatus, is simple and quick to do, and can be used on soils taken during routine sampling for fertility measurements. In this work the test showed the

essential differences between sands and clays, and distinguished the different effects of FYM and of grass on soil structure. But its value for farmers cannot be assessed until many soils have been examined. (Williams and Cooke.)

Field and Laboratory Experiments on N, P and K Fertilisers

" Micro-plot " experiments

Much of the Department's field work on soil and crop nutrition problems is with " micro " plots (4–12 sq. yd.). Experiments with such small plots are used when land is limited—several new experiments have been superimposed on the large plots of some of the old Classical Experiments. They are also essential when many materials or treatments to be tested make " farm-scale " experiments too unwieldy. Micro-plot techniques suffice where yields need not be related closely to agricultural practice and where crop composition is important. The work is exacting, and much must be done by hand; all operations must be more careful and uniform than is necessary when larger plots are used. Errors with small plots and larger plots have been similar, and micro-plot technique is now one of our standard working methods. Much more field experimentation of this kind has been done by the Department recently by limiting ordinary experimentation on commercial farms. A skilled team under Penny (and in association with Widdowson) now provides this service to the Department. Most of the field work reported here has been made possible by this change.

Timing of nitrogen dressings for winter wheat

Seventeen experiments done from 1958 to 1960 measured the worth of autumn seedbed-dressings of N for winter wheat, in terms of equivalent spring top-dressings applied either early (in March) or late (in May). Combinations of these three times of manuring were also tested. Table 3 summarises fourteen experiments on medium-heavy loams giving satisfactory results at harvest. Autumn N increased yields at thirteen of the fourteen centres, but usually by less than equivalent amounts of N given as spring top-dressings. March top-dressings produced the strongest growth, but this was often reflected adversely in severe lodging at harvest. May top-dressings caused very little lodging and usually gave the highest yields. Dividing the lower dressings had no advantage over single May top-dressings, but with the higher level of N, applying half in autumn and half in May, or half in March and half in May, was better than a single dressing. Twelve of the wheat crops followed roots or a legume, and for these May was the best time to apply N. At two centres where the wheat followed a cereal, March N was better than May N, perhaps because it helped to limit damage from " take-all " disease.

Farmers growing wheat on heavy land (and most " wheat-land " is heavy) may apply part of their total N dressing in autumn without losing much fertiliser efficiency, provided the remainder is applied as a " late " (May) top-dressing. This makes " early " (March) spring top-dressing unnecessary, an operation which is often delayed, or made impossible, on heavy land by wet weather. This

work does not apply to wheat grown on light land, where autumn dressings are likely to be leached from light soils; also light land usually provides less N from soil reserves and crops may need early dressings in spring. (Widdowson and Penny.)

TABLE 3

Mean yields of winter wheat grown without nitrogen and the increases given by single and double doses of nitrogen

(14 experiments in 1958–60)

(Yields of grain in cwt./acre at 15% moisture content)

Yield without N fertiliser, 33·2

	Increase in yield from N applied	
	At single rate	At double rate
All in autumn	5·3	8·4
All in March	7·1	8·6
All in May	7·4	9·8
½ autumn and ½ March	6·3	8·4
½ autumn and ½ May	6·1	10·2
½ March and ½ May	6·0	10·1
⅓ autumn, ⅓ March and ⅓ May ...	6·4	9·3

(The rates given were: 0·6 and 1·2 cwt. N/acre in 1958, 0·5 and 1·0 cwt. N/acre in 1959 and 1960.)

Urea for barley on chalk soils

Table 4 gives mean yields from three experiments on Chalk soils in which urea was compared with ammonium sulphate. Each fertiliser was tested when broadcast, combine-drilled (in contact with seed) or placed 1 inch to the side of the seed; the rates used supplied 0·35 and 0·70 cwt. N/acre. Broadcast urea was consistently superior to broadcast ammonium sulphate at each centre at each rate. Combine-drilled urea checked growth slightly at two centres, but did not affect yield; at the third centre drilling urea checked growth severely and gave lower yields than broadcasting.

TABLE 4

Mean yields of grain in three 1960 barley experiments

(Cwt. of grain/acre, at 15% moisture content)

Yield without N, 20·4

	Yield with N applied at					
	0·35 cwt. N/acre			0·70 cwt. N/acre		
		Placed			Placed	
	Broadcast	In contact with seed	At side of seed	Broadcast	In contact with seed	At side of seed
Ammonium sulphate ...	27·2	28·8	29·5	31·9	33·2	34·5
Urea ...	28·1	28·3	29·0	32·5	31·7	34·0

Slight checks to early growth from combine-drilling ammonium sulphate did not affect yields, and drilling was better than broadcasting. Urea placed 1 inch to the side of the seed did no damage and gave better yields than broadcast urea. Side-placing

was slightly better than combine-drilling ammonium sulphate. (Widdowson and Penny.)

Ammonium sulphate, "Nitro-Chalk", urea and calcium nitrate for spring wheat and barley

Each fertiliser was compared broadcast, combine-drilled in contact with the seed, placed 1 inch to the side of the seed or top-dressed in early May. At Rothamsted spring wheat was checked by 0·8 cwt. N/acre broadcast as calcium nitrate, but not by broadcasting the other N fertilisers. Combine-drilling 0·4 cwt. N/acre as calcium nitrate checked growth, and this amount as urea caused a slight check. Combine-drilling 0·8 cwt. N/acre checked growth with all the fertilisers, most with calcium nitrate. Placing these fertilisers 1 inch to the side of the seed caused no damage. Yields at harvest showed no consistent differences between methods of application. Ammonium sulphate gave lowest yields and calcium nitrate the highest, perhaps because the wheat was grown on a freshly limed but previously acid clay-loam. At Woburn similar comparisons at 0·3 and 0·6 cwt. N/acre were made on barley. Initially there were slight checks from broadcasting 0·6 cwt. N/acre as calcium nitrate and from combine-drilling 0·6 cwt. N as urea or calcium nitrate, but these effects were less than those on wheat at Rothamsted. Drilling ammonium sulphate gave better early growth than broadcasting, but there was no visual benefit from combine-drilling or side-placing the other forms of N. At harvest, May top-dressings gave the highest yields with each fertiliser. (Widdowson and Penny.)

Tests of concentrated fertilisers and forms of nitrogen

A concentrated fertiliser (20% N, 10% P_2O_5, 10% K_2O) gave slightly higher yields of kale and Italian ryegrass than an equivalent mixture of ammonium sulphate, superphosphate and muriate of potash. The fertilisers supplied 1·0 and 2·0 cwt. N/acre for these two crops. In a test on barley 0·3 and 0·6 cwt. N/acre was applied, and 20 : 10 : 10 was the better fertiliser at the double rate. The experiment also compared ammonium sulphate, ammonium nitrate, calcium nitrate and urea for the same crops and levels of N. 2·0 cwt. N/acre as calcium nitrate of urea checked early growth of grass and kale; there were slight checks from ammonium sulphate and ammonium nitrate; 2·0 cwt. N/acre as calcium nitrate reduced yields of kale and the first cutting of grass. There was no consistent difference between yields from the other forms of N. Calcium nitrate was safe when only 1·0 cwt. N/acre was applied, and this dressing gave the highest yields of kale at this level of manuring. Ammonium nitrate gave the highest yields of grass (at 1·0 cwt. N/acre). At the second cutting of grass (grown on the residues from spring dressings of N) urea gave lower yields than the other forms at each level of manuring. For barley, ammonium sulphate and ammonium nitrate were best. (Widdowson and Penny.)

Effects of preceding one-year leys on nitrogen manuring of wheat

The Ley–Arable Experiments indicate roughly the adjustments that are needed in nitrogen manuring of arable crops that follow

3-year leys; but there is little modern information on the contribution made by 1-year leys to the N needed by following cereals. Pure stands of late flowering red clover (S.151) and of Italian ryegrass. (S.22) were cut once and twice respectively for silage and then ploughed before sowing winter wheat. Three levels of N were tested on the 1959 ryegrass and four levels on the 1960 wheat. Table 5 gives yields of the 1959 forage crops and the 1960 wheat: Yields of wheat shown were obtained without N and with the highest dressing of N (0·75 cwt./acre); the response curves showed that at least this amount was needed on all plots. When the 1960 wheat

TABLE 5

Yields of forage crops in 1959 and of the following wheat crops

		Forage crops grown in 1959			
		Clover	Ryegrass		
	Cwt. N/acre in 1959	0	0	0·75	1·5
1959	Yields (cwt. dry matter/acre)	49·1	30·6	68·5	76·6
1960	Wheat yields (cwt./acre with 15% moisture)				
	Grain {without N	34·3	29·7	31·4	32·7
	Grain {with N	45·3	47·9	44·5	43·5
	Straw {without N	27·9	20·7	25·9	23·0
	Straw {with N	35·2	31·1	31·3	27·7

was grown without N fertiliser clover was the best preparation, but N given to preceding ryegrass gave small increases in yield. When 0·75 cwt. N/acre was applied the highest yields were after ryegrass that received no nitrogen, with clover the next best, but yields following ryegrass dressed with N were less. This may be because the heavy crops of ryegrass grown with N removed much K from a soil containing little available K. Further, potash was not given to the leys, although the wheat had 0·4 cwt./acre K_2O by combine-drill. Results discussed on p. 46 show that high levels of soil K can give yields that may not be attained by fresh fertiliser dressings. (Widdowson and Penny.)

Nitrogen manuring of different grass species

In planning experiments with grass as a test crop the relative responses to N of different species of grasses should be known. In spring 1958 pure swards of cocksfoot (S.37), meadow fescue (S.215), perennial ryegrass (S.24) and timothy (Scotia) were sown direct. The leys were cut twice in 1958, three times in 1959 and twice in 1960; each was grown without N and with 0·3 or 0·6 cwt. N/acre as " Nitro-Chalk " for each cut, 0·5 cwt. P_2O_5 and 1·0 cwt. K_2O/acre was given to all plots annually. Table 6 shows total dry matter produced from each ley over the three years and the effect of this cropping on the level of dilute acid-soluble K in the surface soil immediately before ploughing in August 1960. Without N, cocksfoot was less productive than the other species; but with N, cocksfoot gave most dry matter at each level of manuring; timothy was almost equally productive when N was used, but ryegrass and

meadow fescue were inferior. The tests for available K show heavy N manuring of grass decreases reserves of soil K; the basal dressing of K used would often be considered adequate for practice, but, clearly, it was far too little. (Widdowson and Penny.)

TABLE 6

Total yields of grass species manured with three levels of nitrogen for three years and the soluble potassium in the soils at the end of the experiment

	Dry matter (cwt./acre)			Soluble * K (mg./100 g. of soil)		
Cwt. N/acre/cut ...	0	0·3	0·6	0	0·3	0·6
Cocksfoot	45·3	162·5	237·0	15	9	5
Meadow fescue	56·6	144·3	191·1	20	13	7
Ryegrass	57·9	134·4	187·2	16	10	7
Timothy	56·8	158·1	211·7	16	8	7

* K soluble in 0·3*N*-HCl.

Autumn nitrogen for Italian ryegrass

Autumn N, applied on 14 November as ammonium sulphate or calcium nitrate, was much inferior to equivalent spring dressings applied on 5 February for Italian ryegrass grown on a light sandy loam and for a similar ley on a clay-loam soil. Ammonium sulphate and calcium nitrate behaved similarly. Yields of dry grass harvested on 5 April were: 2·1 cwt./acre without N, 4·1 cwt./acre from the November dressing and 8·8 cwt./acre from the February dressings. (Widdowson and Penny.)

Comparisons of solid nitrogen fertilisers with solutions

An experiment at Rothamsted on newly sown Italian ryegrass tested ammonium sulphate, ammonium nitrate and sodium nitrate applied at 0·5 and 1·0 cwt. N/acre as solids and as solutions containing 5% N. Solid ammonium sulphate gave higher yields of dry grass and higher N uptake than the same fertiliser applied in solution. Differences between yields from solid and liquid forms of the other two fertilisers were not significant. (Nowakowski and Penny.)

The effects of nitrogen fertilisers on the forms of soluble nitrogen in grass

Work on the accumulation of various forms of soluble nitrogen in grass after manuring with different N fertilisers was continued, and a field experiment on Italian ryegrass at Rothamsted confirmed previous results. Grass receiving ammonium nitrate and sodium nitrate contained much more NO_3-N than grass supplied with ammonium sulphate; 10 days after applying ammonium nitrate grass contained 0·92% NO_3-N in the dry matter and after ammonium sulphate 0·56%. Grass given ammonium sulphate contained more NH_4-N, amide-N and α-amino-N than grass given ammonium nitrate or sodium nitrate. One month after applying the dressings, all the NO_3-N contents of the grass had decreased, but the difference in NO_3-N level between grass receiving nitrate fertiliser and grass receiving ammonium sulphate became greater. Grass grown with solid fertilisers and with solutions had similar NO_3-N contents 10

days after the fertilisers were applied, but 3 weeks later grass given solid forms had twice as much nitrate as grass given solutions. (Nowakowski.)

Comparisons of potassium fertilisers

Comparisons of muriate of potash with potassium sulphate and potassium bicarbonate begun in 1959 (*Rep. Rothamst. exp. Sta.* for 1959, p. 51) were continued. At Woburn all forms of K lessened potato yields, which were less with the double dose of K than with the single. The losses were least with bicarbonate and greatest with muriate, which depressed yields by as much as 3 tons/acre. At Rothamsted K manuring increased yields considerably. Two levels of N were tested; with 0·75 cwt. N/acre, muriate was the best form of K, but with 1·5 cwt. N/acre, the double dose of potash lowered yields—muriate by 3½ tons/acre and sulphate by nearly 1 ton/acre. Bicarbonate did no damage; but it was inferior to the other two forms of K at the low rate of N; at the high rate of N it gave lowest yields with K at the lower rate, but it gave the highest yield at the higher K rate. (Widdowson and Cooke.)

Rothamsted reference plots

A micro-plot rotation experiment was established in spring 1956 on Great Field IV after ploughing very old grass. Responses to N, P, K and to FYM are measured on a five-course rotation of wheat, kale, barley, clover–grass ley and potatoes. The standard factorial lay-out testing all combinations of N, P and K (eight plots) was supplemented with four additional treatments testing double dressings of N (with PK), and also FYM with and without fertilisers.

Although the soil had long been under grass and was high in total N, all crops except clover responded well to fertiliser N. Kale and permanent grass especially depended on N for high yields, and both needed the full dressing of 2·0 cwt. N/acre. Kale and potatoes were the only crops to benefit appreciably from P fertiliser. Wheat, clover and potatoes all gave large responses to K. Only barley gave regular and similar responses to N, P and K. FYM improved yields of all crops, even when NPK was also applied, and potatoes, kale and clover responded particularly well.

A similar experiment was begun in 1960 on old arable soil on Stackyard Field, Woburn; sugar beet and oats replace kale and winter wheat, and there is a strip of plots with soft fruit bushes. All crops except clover gave very large responses to N in 1960, P and K increased yields only little. (Widdowson, Penny, Cooke and Williams.)

Phosphate fertilisers

Previous work, mostly in collaboration with N.A.A.S. Soil Chemists, valued fertilisers that could serve as alternatives to superphosphate for annual arable crops and for grass. On very poor soils, and with crops that are specially sensitive to P-deficiency, the "starter" action of phosphate for young plants may be very important. For such quick action, water-soluble phosphates have obvious advantages over insoluble materials, but we know little

about *rates of action* of fertilisers that are insoluble, or only partly soluble in water. Nor do we know enough about residual effects of alternative phosphate fertilisers, and these are at least as important as immediate effects where the main value of new dressings is to maintain reserves of soil P. Experiments were therefore started both on rates of action and on residual values of a range of phosphate fertilisers.

Rates of action of phosphate fertilisers

Micro-plot experiments on ryegrass grown on acid soils were done in 1959 and 1960 to test superphosphate, dicalcium phosphate, potassium metaphosphate, basic slag, Gafsa rock phosphate and three granular nitrophosphates having none, one-quarter and one-half of their total P water-soluble. Grass sown in 1959 grew slowly because of drought and was not cut until April 1960. There were good responses to superphosphate and dicalcium phosphate, both of which gave equal yields; none of the materials tested was significantly different from these two standard fertilisers. Grass sown in 1960 grew more rapidly, and the first harvest was taken after 14 weeks. Powdered dicalcium phosphate dihydrate gave higher yields than granular superphosphate; all the phosphates tested (except potassium metaphosphate) gave significantly less grass than did dicalcium phosphate. Gafsa rock phosphate and basic slag were significantly inferior to superphosphate. Nitrophosphate with no water-soluble P, gave less grass than the other nitrophosphates.

The second harvest, 22 weeks after sowing, showed dicalcium phosphate and superphosphate to be nearly equal; Gafsa rock phosphate and the nitrophosphate with low water-solubility had both improved and gave significantly more grass than superphosphate. The total yield for the two cuts showed powdered dicalcium phosphate to be significantly better than granular superphosphate, which, in turn, was not significantly different from any of the other phosphates tested. This experiment showed the expected differences in rates of action. Rapid action, illustrated at the first cutting, was obtained from water-soluble materials and from finely powdered dicalcium phosphate (perhaps because it had a high surface area), but the slower materials were more effective later and, over the whole season, differences between materials were less than at first. The consistent superiority of powdered dicalcium phosphate dihydrate over granular superphosphate was significant in these 1960 experiments. In earlier work the two materials were more nearly equivalent. (Mattingly and Penny.)

Residual values of phosphate fertilisers

In two experiments designed to last 6 years and started in 1959, heavy dressings (3·0 cwt. P_2O_5/acre) of the phosphate fertilisers listed in the previous section were mixed with surface soil by ploughing and rotary cultivating in autumn/winter 1959. The first crops were sown in 1960, when new small dressings of superphosphate were applied to provide a scale for measuring residual effects of the larger dressings applied in 1959. Residues from 3 cwt. P_2O_5/acre given as superphosphate in 1959 gave larger yields of swedes,

potatoes and barley in 1960 than a new dressing of 0·5 cwt. P_2O_5 broadcast before sowing. Gafsa rock phosphate residues gave significantly less potatoes than superphosphate residues, but the other phosphates were not significantly different from superphosphate. For swedes all the fertilisers tested had similar residual effects. (Yields given by nitrophosphates in 1960 were not a good indication of the value of the phosphate, because these are NP fertilisers and about 3 cwt. of extra N/acre had to be applied with the P dressing and this had not leached completely from the soil by summer 1960.) (Mattingly.)

Urea

Urea is potentially valuable as a fertiliser because it is highly concentrated and cheap to make, but experiments in the last few years have shown that it may have disadvantages. Some samples, particularly of granulated products that have been heated in processing, may contain biuret, which is toxic. The other disadvantage, common to all samples, is that when urea decomposes rapidly ammonium carbonate or bicarbonate is formed, and the pH near to the fertiliser particles rises. High pH and high ammonia concentrations near to young seedlings may damage them—this happened in barley experiments reported last year. The same decomposition may also lead to loss of N (as NH_3 gas) (and therefore reduced efficiency) when urea is applied as a top-dressing for grass or arable crops, or when it is not buried deeply enough in a seedbed.

Losses of nitrogen from urea applied to soils

In laboratory experiments, urea equivalent to 0·9 cwt. N/acre was applied in different ways to several soils at each of several water contents and at 5° and 25°. Air was passed over the soils and the NH_3 lost was measured. Losses were more serious from light than from heavy soils. The least loss of N (<1%) was from heavy soil at 5°, the greatest (20%) from light soil at 5°. Except with a light soil containing little organic matter, losses were less when urea was mixed with the surface inch than when it was broadcast on the soil. Changes in moisture content of soil within the range 40–60% of the water-holding capacity generally made little difference to losses of NH_3, but again the poor light soil was an exception, at 25° much more NH_3 was lost from the driest sample. Temperature had little effect on total losses of NH_3 but they occurred much more quickly at 25° than at 5°. The exception was again the light soil with low organic matter, from which twice as much NH_3 was lost at 5° as at 25°. (Gasser.)

Effects of biuret and urea on germination

The effects on germination of kale of samples of urea having different biuret contents were measured in a field experiment. The fertilisers were tested at 0·9 and 1·8 cwt. N/acre, both broadcast on the surface and placed immediately under the seed, which was sown in rows 9 inches apart. Germination percentages, averaged for the rates and methods of application and taking the plants established on unfertilised plots as 100%, were: granular urea (6% biuret) 56%, prilled urea (1·5% biuret) 85%, crystalline urea (0·6% biuret)

71%, pelleted urea (0·5% biuret) 82%, ammonium sulphate 73% and calcium nitrate 91%. Only the granular urea was more dangerous than ammonium sulphate or calcium nitrate. Damage was greater at the higher rate of dressing and also when the fertilisers were placed directly under the seed. (Gasser and Penny.)

In a pot experiment with kale high rates of urea usually depressed germination, with no difference between the four samples; germination was higher in moister soil. Yields and total-N uptakes at harvest were proportional to biuret contents, and were least with the sample containing most biuret. (Gasser and Close.)

Experiments in Forest Nurseries

Long-term rotation experiments

In 1951 two long-term rotation experiments of about 350 plots each, cropped with Sitka spruce seedlings or transplants, were laid down in nurseries at Wareham (Dorset) and Kennington (Oxford). (Their design and lay-out is described in *Rep. For. Res. For. Comm.* for 1952–53, pp. 84–100.) The experiments compare continuous conifer cropping with a rotation in which one conifer crop in three is replaced by either bare fallow or a " green " crop (rye, ryegrass or yellow lupins); they also compare annual applications of compost made from bracken and hop-waste with a mixture of " Nitro-Chalk ", superphosphate, KCl and $MgSO_4$. Over eight seasons there has been no advantage, at either centre, from interrupting continuous cropping with conifers by any of the three green crops, but at Kennington bare fallow improved growth. At both centres fertiliser-grown seedlings have been 20–30% larger than those having compost.

In a supplementary experiment on continuously cropped seedbeds, compost and fertiliser each increased seedling height; at Wareham the unmanured crop failed completely. At *Kennington* compost and fertiliser applied together were no better than fertiliser applied alone, but at *Wareham* the two manures together produced larger plants than either material applied alone. This result might indicate that compost had other functions besides supplying nutrients, but there is no present evidence that this is so. The fertiliser-grown plants suffered from Cu deficiency (*Nature, Lond.* (1956), **178**, 864), and in several seasons also showed K-deficiency symptoms. During wet seasons compost plots, as well as fertiliser-treated plots, pass through periods of nitrogen deficiency, and these periods are rarely coincident on the two kinds of plots. Therefore plants grown with compost plus fertiliser have received a steadier supply of N, and have been less subject to either K or Cu shortages. The experiments are being modified to eliminate, as far as possible, differences that may come from lack of nutrients in the fertiliser. (Benzian.)

The problem of " worn-out " nurseries

In some of the Forestry Commission's nurseries (mostly those started on farming land between 1920 and 1940) some conifers, such as Sitka spruce, *Tsuga heterophylla* and *Pinus contorta* remain small and stunted, even with ample plant nutrients applied either as

compost or fertiliser. This stunted growth normally occurs on soils with high pH, but there are exceptions, such as failures on acid soil at Ringwood. In several nurseries stunting is associated with root damage caused by fungi and, at Ringwood, with root-parasitic nematodes as well. Root damage of either kind is greatly decreased by " partial sterilants " such as formalin and chloropicrin; but these materials are also of benefit where no effects from pests and pathogens have yet been recognised. Improvements have even been observed in highly productive nurseries like Wareham, where growth seems normal.

It is difficult to isolate the factor or factors responsible for stunting and for the dramatic improvement in growth with " partial sterilisation "; members of several departments at Rothamsted are working together on the problem. Materials like steam, formalin and chloropicrin not only profoundly change the soil flora and fauna, but chemical changes in the soil may alter nutritional conditions, such as producing and maintaining a higher concentration of ammonia. " Partial sterilants " and acidifying agents both tend to increase the amount of Mn in seedlings, and the untreated plants may well suffer from Mn and/or Fe deficiency. Mn as well as Fe chelates have been tested as foliar sprays, but so far without success in the nurseries, and with only very slight benefit from Mn chelate in pots.

As stunting is confined to older nurseries, it is important to discover whether, with modern manuring, cultivation and weed control, nurseries can remain fertile indefinitely. The two long-term rotation experiments mentioned above will indicate problems that may come from intensive conifer cropping. Although during the first eight seasons, there were no signs of deterioration in growth resembling the troubles encountered in " worn-out " nurseries, size (1959) and plant number (1960) were much decreased on many compost-treated plots at Kennington. In 1959 the Wareham plots suffered from an attack of *Fusarium* wilt, which was much more severe with compost than with fertiliser. The future will show if these failures are isolated occurrences or if they are the first indications of a gradual deterioration. (Benzian.)

Tests on soil diluents

Most recent work on partial sterilisation has been done at Ringwood and Old Kennington Nurseries; at both, but particularly Ringwood, poor soil structure is likely to have contributed to stunted growth. Close packing may interfere with supplies of water and air, as well as with drainage, and may obstruct growing roots and so favour attacks by parasites. To open up the soil, two materials were incorporated into the top 6 inches a few weeks before sowing: 12 lb./sq. yd. of coarse-grade sedge peat and 100 lb./sq. yd. of quartz grit from St. Austell. At Old Kennington the diluents were tested together with formalin; at Ringwood bad weather made this impossible. In the Old Kennington experiment, peat alone increased height by 40% and formalin alone by 70%. With formalin, peat improved growth only slightly; and with peat, the response to formalin was lessened. Bad physical conditions may have aggravated attacks by pathogens. However, in the very

wet 1960 season part of the benefit from peat may have been from a slow release of N. At Kennington there was no response to St. Austell grit. At Ringwood peat improved growth but, in contrast to Kennington, the nutritionally inert quartz grit gave a slight benefit. (Benzian.)

Anion–Cation Relationships in Crop Nutrition

Uptake of nutrient cations by crops is usually decreased by other cations present in the soil; similar effects exist with anions. Uptake of positive (or negative) ions is also affected by the presence of ions of opposite charge. These relationships are particularly important when heavy dressings of fertilisers are used, and they are more pronounced on light than on heavy soils. Such effects alter the efficiencies of nutrients supplied as fertilisers, affect the use that plants make of nutrients in soil and may influence the quality of crops. As there is little systematic information, work began in summer 1960 to obtain information about ion relationships. Micro-plot field experiments done with ryegrass and kale on heavy soil at Rothamsted will extend to light soil at Woburn in 1961. The effects of combinations of fertiliser salts on crop composition are being examined. (Cunningham.)

Nitrogen in Soils

Using the mass spectrometer for determining ^{15}N

Almost all of Newman's time was spent in making the mass spectrometer (*Rep. Rothamst. exp. Sta.* for 1959, p. 41) work satisfactorily and in establishing a service for determining ^{15}N in soils and plant materials. The instrument has been used effectively since May 1960.

The steps in the analyses of the samples are: (i) Kjeldahl digestion; (ii) distilling the digest from alkali and then titrating with acid; (iii) converting ammonium salt solution to nitrogen gas; and (iv) analysing the gas sample in the mass spectrometer. Each step can lead to errors in the final ratio of ^{15}N : ^{14}N and each has been examined to make the total error small.

Some workers state that Kjeldahl digestion can lead to an impurity (possibly methylamine), which gives ions of mass/charge ratios of 45, 31 and 29; this is particularly likely with Cu–Se catalysts (which we generally use), but it never happens with Hg catalyst. During the mass spectrometric analysis of N, the ratio of ions 28 ($^{14}N_2^+$) to 29 ($^{14}N^{15}N^+$) is measured, and the impurity leads to an over-estimate of ions $^{14}N^{15}N^+$, giving an erroneously high ratio of ^{15}N : ^{14}N. Samples from incubation experiments with soil and straw (described below) gave this impurity (which was diagnosed by ions produced at mass 31), and it prevented reliable estimates of ^{15}N in these samples. In further work soils alone were digested with Cu–Se, and with Hg catalysts and soil–straw incubations were digested with Cu–Se catalysts. No trace of this impurity was found in any sample, and ^{15}N : ^{14}N ratios were normal. It is considered the " impurity " was caused by too short digestion time.

During distillation of the digests a sample high in ^{15}N may leave

a micro-amount of ^{15}N, which may contaminate a following sample having normal ^{15}N content. In distillation tests where appreciable contamination occurred only with 14% of ^{15}N, distilling several blanks eliminated the effect.

Converting NH_4 solutions to N_2 gas is tedious, as all air must be removed from the solutions to prevent diluting the ^{15}N content in the sample. Only small quantities of N_2 are needed for analysis, and good high-vacuum technique is essential; we have been able to convert only five or six samples per day. A simpler technique is now being tested.

Consistent results are obtained only by standardising operations rigidly. Calibrating the resistance chain on which the final ratio depends showed maximum error of about −11% and ratios are now corrected to allow for this. The instrument shows "mass descrimination" errors and tends to over-estimate the lighter mass ions at the expense of the heavier; this over-estimate increases as the sample is consumed during analysis. Extensive modification would be necessary to lower this mass descrimination; but for the ratio 28 : 29 the effect is small enough to be neglected, the ratios obtained from the Kjeldahl experiment described above were examined statistically and found to be accurate enough for determining small enrichments with ^{15}N. For greater enrichments of ^{15}N, the few results show errors of ±5%; more work is being done to improve this.

For other mass ratios, e.g., N_2 to O_2, or N_2 to A (both necessary for correcting nitrogen samples for the presence of air), the results have not been very consistent; apart from the mass descrimination effect mentioned above, $N_2 : O_2$ has varied from 5·5 to 6·1 (the volume composition of air gives 3·7), and although it is not unusual for mass spectrometers to give a value for this ratio of 6, its variability makes correcting for air in the samples rather uncertain. Using the instrument for gas analysis is also hindered by this inconsistency.

With an assistant preparing gas samples from NH_4 solutions, we have been able to analyse 20–25 samples each week. 200 samples have now been analysed, over half of which were for members of the Soil Microbiology Department. (Newman.)

Non-symbiotic fixation of nitrogen

Detectable amounts of N can be fixed when soil is incubated with much (13%) added straw carbon (for example, J. M. Bremner, *J. agric. Sci.* 1958, **51**, 23). Using ^{15}N in the mass spectrometer measures N fixation more sensitively than the Kjeldahl method used by Bremner, and work was done to see whether there is any fixation with small amounts of straw under aerobic and anaerobic conditions. Straw (1% addition of straw carbon) was mixed with calcareous soil low in organic matter, and the soil alone, soil + straw, and soil + straw + KNO_3, were incubated for 42 days in atmospheres containing N_2 gas enriched with ^{15}N. The 250 p.p.m. of NO_3-N added more than sufficed for the microbial population attacking the straw and (under aerobic conditions) NO_3-N did not fall below 67 p.p.m., in contrast to treatments with straw alone, with which the initial NO_3-N of the soil (15 p.p.m.) fell to zero in

20 days and did not increase again. Four atmospheres were used: aerobic with removal of CO_2, aerobic allowing CO_2 to accumulate, anaerobic with removal of CO_2 and anaerobic allowing CO_2 to accumulate. The nitrogen gas contained 6 atom % excess ^{15}N, although in a few experiments a 20 atom % excess was used. Total N in the incubated soils, as determined by Olsen's modification of the Kjeldahl procedure, showed no fixation in any of the treatments; in the anaerobic treatments NO_3 had been quantitatively lost in contrast to the aerobic treatments, where there was no loss of added NO_3. Determining ^{15}N in the Kjeldahl distillates was difficult because of an unidentified contaminant discussed above (possibly methylamine), which increased the height of the ^{15}N peak in the mass spectrometer. Some samples therefore showed an *apparent* fixation of nitrogen which was not caused by an excess of ^{15}N. But " fixation " (real + apparent) was never greater than 10 p.p.m. of N. (Jenkinson, Birecki, Newman.)

Some other factors governing non-symbiotic fixation of N are being investigated. The amount of N fixed when straw was added to water-logged soil under anaerobic conditions increased linearly with straw additions of 2·5–20%, were maximal when 30% was added and fell with larger additions. The maximum fixation (50 mg. N/100 g. of soil or 1·7 mg. N/g. of straw) was the same in old arable soil and old grassland soil. (Jenkinson and Barrow.)

The effects of 1-year leys and fertilisers on soil nitrogen status

A field experiment (done by Widdowson and Penny and described above, p. 52) measured the effects of growing clover or ryegrass on the N needed by following wheat. Soil samples from this experiment showed differences in N status. When the leys were ploughed in autumn plots where clover had grown contained more mineral-N, and more N that could be mineralised in laboratory incubations, than plots where ryegrass had grown; giving N-fertiliser to the ryegrass raised the N residues left in the soil. These differences in N-status disappeared by the following spring.

In another field experiment (*Rep. Rothamst. exp. Sta.* for 1958, p. 46) urea–formaldehyde (UF) fertiliser was compared with " Nitro-Chalk " (NC); UF was much less efficient than NC for 2 years of cropping with grass, presumably because it did not decompose quickly or completely enough. In the following spring, when cultivations were complete, levels of mineral N in the soil were higher on plots fertilised with UF than on unfertilised plots. Increases (in p.p.m.) of NH_4-N+NO_3-N on incubating the air-dry soils were:

Treatment in the field experiment		Mineralisable N	
		Autumn	Spring
1958	1959	1959	1960
None		36	39
—	NC	41	41
—	UF	52	50
NC	—	43	38
UF	—	47	41
NC	NC	41	39
UF	UF	62	54
Significant difference (P <0·05)		8·7	9·1

Inorganic N fertiliser had little effect on the N reserve of the soil, but applying UF in spring 1959 significantly increased the mineralisable-N in both autumn and spring 1959/60; UF given to plots in 1958, with none in 1959, had much less effect on the soil than the 1959 dressings. (Gasser.)

Soil Phosphate

Losses of phosphate from sandy soil

In a field experiment on very light and acid (pH 4·5) sandy soil in the Forestry Commission's Research Nursery at Wareham (Dorset) several phosphate fertilisers equivalent to 16 mg. of P/100 g. of soil were applied between 1955 and 1959. Samples taken at the beginning and end of the period showed the following changes in total P contents and in isotopically exchangeable P ("A" values) measured in pot experiments on ryegrass:

Annual treatment	Changes from 1955 to 1959	
	Total P	"A" value
	mg. P/100 g. of soil	
No phosphate	−1·0	−0·1
Superphosphate	−0·4	+1·1
Basic slag	+4·3	+4·2
Gafsa rock phosphate	+9·8	+3·8

Yields of grass in pot experiments on the soils were highest with basic slag and rock phosphate and much less with superphosphate; differences in favour of the less-soluble materials were much greater in 1959 than in 1955. The total P content of the soil, 5·6 mg./100 g. in 1955, declined during the period on the "no phosphate" and the superphosphate plots, but rose on the basic-slag plot by one-half, and on the plot receiving rock phosphate it doubled. All the superphosphate not used by the crops grown had leached out in the 4 years, and three-quarters of the P applied as basic slag and half of that added as rock phosphate had also probably been lost. Rock phosphate and basic slag clearly have much greater residual values than superphosphate.

Table 7

Changes in P content of sand and silt fractions between 1955 and 1959 (in mg. P/100 g. of soil)

Particle size range (microns)	Phosphate applied as		
	Super phosphate	Rock phosphate	Basic slag
2,000–200	+0·3	+2·0	+0·5
200–75	−0·5	+5·0	+0·7
75–20	−0·3	+1·3	+0·9
20–5	+0·9	+1·3	+1·3
Total	+0·4	+9·6	+3·4

Measuring the total P contained in four size fractions of the soil separated by sedimentation (Table 7) showed little change from adding superphosphate, but considerable changes from adding the other phosphates, and particularly rock phosphate. Three-quarters

of the total P accumulated in the rock phosphate plots was in the coarse and fine sand fractions. All the fractions were enriched by basic slag, but the fine material more than the coarse.

Distribution of phosphate was also measured in an acid clay soil at Rothamsted used for a field experiment testing superphosphate and rock phosphate (described in *Rep. Rothamst. exp. Sta.* for 1959, p. 49). Most of the extra phosphate supplied by superphosphate was in the clay and silt. Phosphate had accumulated in the fine sand (200–75 μ) fraction only on plots treated with rock phosphate. This confirms the result at Wareham and suggests that rock phosphate accumulates in acid soil as undissolved particles. (Mattingly.)

Fractionating inorganic soil phosphorus by ion-exchange resins

The rates were measured at which Ca, Al, Fe and P are removed from soil (<40 mesh) in 10% aqueous suspension by Cl′-saturated Amberlite IRA-401 (20–30 mesh) and Na-saturated Zeo-Karb 225 (10–20 mesh) exchange resins. (The resins were rapidly and completely separated from soil by stainless-steel sieves.) Varying the "wet resin" : soil ratio suggested an optimum weight ratio of 1·5 : 1 for both anion- *and* cation-exchange resins to remove most phosphate ions and cations from the soil at equilibrium. In IRA-401 (AER) and Zeo-Karb 225 (CER) respectively this weight ratio is equivalent to average values of 55 : 1 and 35 : 1 for the ratio of the *total* exchangeable ions in the resin to those in the soil. Phosphate was not recovered completely from AER by successive extraction with 0·01*M*–2·0*M* solutions of Na_2SO_4, NaCl and NaOH (even on boiling), and the resin had to be incinerated at 550° before analysis. Before extracting with resins, the soils were brought to equilibrium with carrier-free ^{32}P for 320 hours to label the isotopically exchangeable phosphate uniformly. The rate of change of the specific activity of P removed from soil by resin was measured.

Soils provided by Mr. J. W. Blood (N.A.A.S., East Midlands Region) in 1958 from unmanured and phosphate-treated sections of a field experiment at Shardlow (Nr. Derby) were examined. The phosphate extracted from soils that had been maintained in the field at pH 4 or pH 6, with CER or AER, had a constant specific activity at all times, indicating that each extracting mechanism removed only part of the isotopically exchangeable phosphate (P_e). The amount removed in 1 day was directly proportional to P_e, and was larger with the soil of higher pH. Equilibrium was reached rapidly with CER, but with AER 12 days contact was required. The fraction of P_e extracted by AER increased only slightly with increase in soil pH (which remained constant during extraction). By contrast, CER extracted approximately twice as much of the total P_e from soil with pH 6 than from soil with pH 4, and during extraction with this resin the pH rose by 1–1·5 units. Table 8 shows that the total phosphate ions removed by AER plus CER are equal to the "rapid" isotopically exchangeable phosphate "P_r". Therefore phosphate ions in "P_r" are held: (*a*) as anions compensating positive charges on the soil, and (*b*) as counter ions associated with cations in the ion atmosphere surrounding the soil colloid. The proportion of P_r held on positively charged sites diminishes

with increasing soil pH, and a larger proportion appears as counter ions in the micellar liquid.

The specific activity of phosphate extracted by a mixture of AER plus CER falls slowly after several days' reaction with soil, indicating that non-isotopically exchangeable forms of phosphate are extracted together with P_e. When completed this work will clarify the nature of slowly exchanging and non-exchangeable forms of soil phosphate and their relationships with soil pH.

TABLE 8

Phosphate removed by AER and CER from two Shardlow soils in 1 day and the isotopically exchangeable phosphate in mg. P/100 g. of soil

	Soil of pH 4·2		Soil of pH 5·9	
Field treatment	No P	P	No P	P
Phosphate removed				
By Cl′–AER ...	3·7	6·3	5·1	6·9
By Na′–CER ...	1·9	3·7	6·5	9·0
Total with resin	5·6	11·0	11·6	15·9
Isotopically Exchangeable				
P_r	8·3	12·0	11·3	16·7
P_e	17·6	26·0	28·8	35·3

With partially unsaturated CER $\left(\frac{H}{Na + H} = 0{\cdot}11\right)$, either alone or mixed with AER, non-exchangeable phosphate was removed from soil within ½–1 hour of contact, and soil pH was lowered by 1–2·5 units. (Vaidyanathan and Talibudeen.)

" Available phosphate "

About 180 individual soils, taken from sites of field experiments done between 1951 and 1956 to test P fertilisers, were analysed by seven methods for " readily soluble " P. None of the methods was outstandingly successful in predicting crop responses to P fertilisers. The best methods were those using a slightly acid acetate buffer solution, a solution of 0·5*M*-$NaHCO_3$ or extraction with 0·01*M*-$CaCl_2$ solution. Methods using acetic, citric, sulphuric or hydrochloric acids were less useful. Partial regression coefficients (calculated by J. H. A. Dunwoody) showed that analyses by an individual method rarely accounted for more than half of the variation between the effects of P fertilisers on crop yields; there was little improvement when the values for soluble P determined by two or more methods were used together. The soils used for the field experiments had all been selected as being P-deficient, so they did not extend over the normal practical conditions of extreme shortage to a large surplus of soluble soil P; nevertheless, the soils used ranged from those where arable crops failed without added P fertiliser to those where P fertilisers did not increase yields. This work shows that no close relationship between soluble P determined by a chemical method and uptake of soil P by crops can be expected within the steeply rising part of the curve relating chemical measurements of soluble P to uptake of soil P by crops. Weather, and soil

structure and depth, must affect the accessibility of soil P to roots; pests and diseases may also influence yield and response to P fertiliser. Many similar investigations have produced disappointing correlations between soluble P in soils and effects of P fertilisers on the crops grown, and have tended to discredit soil analysis as a tool for advising on P manuring. Too much attention has been given to erratic relationships between low values for soluble P and the uptake of soil P by crops, and too little to the fact that the better methods of analysis generally predict very well the richer soils where crops obtain enough P without added fertilisers. Future work should aim to establish limiting values for soluble P in soils above which responses to extra P will not be expected, and where P fertilisers will be needed only to maintain reserves. Crops grown on soils with less soluble P will need normal P manuring. (Williams and Cooke.)

All methods used in this country to measure soluble P for advisory purposes are empirical. The better ones often succeed because of compensating errors; they measure a quantity of P that combines the "intensity" of immediately available P that is ionised and the "pool" of useful P that could ionise and which acts as a reserve (the terms were defined by R. K. Schofield (*Soils & Fert.* 1955, **18**, 373–375). In the early stages of growth a crop must depend on the ionised P expressed by the intensity factor, and there is a good argument for using this quantity as a measure of "available" P (and neglecting the reserve in the "pool") for immediate advisory purposes. Schofield gave a theoretical basis for using the amount of soil P in equilibrium with 0·01*M*-$CaCl_2$ solution as a measure of P intensity. This method is therefore being examined for practical limitations or difficulties, and to see if the values are stable throughout the year, and whether they are affected by variations in laboratory techniques. (Cooke, Blakemore and Mattingly.)

Soils from old arable fields where FYM has not been applied within the last 50 years were sampled at different periods during the year. When under fallow or cropped with a cereal, changes in $NaHCO_3$-soluble P within the range 0·3-1·5 mg. P/100 g. of soil show changes of less than 10% during the year. (Warren and Johnston.)

Relationship of soluble P and total P

Soils from the sites of four Classical Experiments (Agdell, Hoosfield Permanent Barley, Barnfield and Exhaustion Land) show that "soluble" P increases with "total" soil P. The increase is slowest for Agdell and fastest for the Exhaustion Land. ("Soluble" P was determined with 0·5*M*-$NaHCO_3$, and "total" P by the perchloric acid method.) With 30-40 mg. "total" P/100 g. of soil, "soluble" P would probably be negligible; the insoluble P includes the stable organic P in soil. (The temperature of the $NaHCO_3$ solution affects the amount of P dissolved, and must therefore be kept within $\pm 1°$ of a selected temperature.) (Johnston.)

Soil Potassium

Categories of soil potassium

In continued glasshouse cropping the amounts of non-exchangeable K released from many soils tend to become directly proportional to time. Extrapolating this rate of release of "native" K to zero time estimates the total uptake of K from other sources. In most soils examined this estimate was much larger than the fall in exchangeable K, showing that a second category of non-exchangeable K contributes to uptake by crops. This category of "loosely held", or "fixed", K can be depleted rapidly; it is not known whether the K is released from vermiculite-type minerals which have fixed K or whether it is from some of the more highly weathered planes in hydrous micas which rapidly lose their remaining interlayer K and expand when exchangeable K is lost. Because the estimated releases of "loosely held" K increased in many soils with the total K contents, and with the amounts of fine-clay, highly weathered hydrous micas may be important sources of this fraction.

Rothamsted soil releases "native" K very slowly, and the "loosely held" K may be largely derived from accumulated residues of K-fertilisers held in vermiculite-type minerals. During exhaustive glasshouse cropping, soils from the Agdell Rotation Experiment released non-exchangeable K at rates that were linearly related to the initial exchangeable K values; this indicates that an equilibrium is established between exchangeable K and "loosely held" K. Ratios for (release of non-exchangeable K) : (fall in exchangeable K) with Agdell soils are about 2·6 for top-soils, and 3·8 for subsoils, whether or not potash fertiliser has been applied. (Arnold and Close.)

Effects of time of sampling and previous cropping on soluble potassium

Soils from old arable fields where FYM had not been given within the last 50 years have been examined at different times of the year and in different years. Under fallow values for soluble K do not vary significantly during the year, or from year to year. On soils with little soluble K, crops with moderate K requirements (cereals) change soluble K little; crops needing much K (kale, swedes, sugar beet) decrease the soluble K values so much that succeeding cereals showed K deficiency symptoms when young. This decrease is only temporary, and soluble K returns nearly to the initial level during the year. On soils having "medium" soluble K the values do not return to their initial levels after growing crops that need much K, but the decrease is less than the amount of K removed by the crop. (Warren and Johnston.)

Measuring "readily-available" potassium

The K status of soils was assessed by measuring the K concentration in dilute solutions of $CaCl_2$ shaken with soil. For calcareous Rothamsted soil cropped with perennial ryegrass in the glasshouse the uptakes of K in the first harvest increased steadily as the free energy of exchange (calculated for the replacement of K by Ca) in the soils decreased over the range 4,300–3,100 calories/g. equivalent.

Yields of grass were greatest when the energy of the K–Ca exchange was less than about 3,700 calories. K uptakes by the grass were better correlated with the energies of exchange than with the exchangeable K contents of the soils.

Cotswold soils, examined in collaboration with Mr. R. D. Russell (N.A.A.S., South-western Region), usually have values for exchangeable or " easily-soluble " K that are poorly correlated with the field performance of crops. Crops on many of the soils yield badly and give little response to K fertilisers; equilibration tests using 0·01*M*-$CaCl_2$ as the " blanketing " electrolyte gave energies of replacement of K by Ca in the range 4,500–3,900 calories. By comparison with Rothamsted soils these Cotswold soils are very deficient in K. In laboratory tests dressings equivalent to 3 cwt./acre of KCl mixed with the Cotswold soils did not change the energies of exchange of K by Ca to levels that favour uptake of K by plants. This may explain the poor response of such soils to K-fertilisers; larger dressings of K fertilisers will be required, or the dressings that are used should be localised near the roots of crops. With some soils having high Ca status and high exchangeable K values, equilibration with dilute electrolyte underestimates the abilities of the soils to supply K to ryegrass in the glasshouse; until such anomalies can be explained the technique cannot be applied generally. (Arnold.)

The Value of Phosphorus and Potassium Reserves in Soils of the Long-term Experiments

Agdell Rotation Experiment

The effects of the residues of P fertilisers, accumulated in the soil during the main period of this Experiment (1848–1951), on yields of barley, potatoes and sugar beet were again measured. Responses to fresh dressings of superphosphate in Table 9 are means from experiments in 1959 and 1960. The three crops responded to new

Table 9

Mean crop responses to new dressings of superphosphate supplying 1·0 cwt. P_2O_5/acre on the site of the Agdell Rotation Experiment

Manuring and rotation treatment in old experiment		Barley grain (cwt./acre)	Potatoes (tons/acre)	Sugar beet roots (tons/acre)	P soluble in 0·5*M*-$NaHCO_3$ mg./100 g. soil
None	Clover	12·7	4·8	2·7	0·4
	Fallow	6·5	5·9	3·8	0·4
PK	Clover	4·4	4·2	1·2	0·8
	Fallow	2·5	2·2	0·5	1·6
NPK	Clover	1·1	2·8	0·7	1·2
	Fallow	0·9	4·0	1·3	1·5

dressings of superphosphate in the same way as in experiments on the Exhaustion Land in 1957 and 1958. Barley and sugar beet used residues of P fertilisers that had accumulated in the soil during the main Rotation Experiment (1848–1951), and where these residues had raised the level of soil P to 1·0 mg. P/100 g. of soil (soluble in 0·5*M*-$NaHCO_3$) fresh dressings of P fertiliser gave only small

increases in yields of both crops. In contrast, potatoes needed fresh P fertiliser, even though this crop removed the same amount of P as barley and less than sugar beet.

The residual effects of a single dressing of superphosphate applied in 1959 at 1·0 cwt. P_2O_5/acre were measured on the three crops in 1960. Table 10 gives the amounts of " new " (i.e., 1960) superphosphate that were equivalent to the residues of the 1959 dressings. These figures are derived from broadcast superphosphate response curves for the range 0·5–1·5 cwt. P_2O_5/acre on plots where the crops responded to these new dressings. On the two soils where crops gave the largest responses to fresh P (clover and fallow sections of the old unmanured plot) the 1959 dressing had high residual values for both barley and sugar beet in 1960. (Two of the four values indicated that residues were nearly equal to a new dressing of the same amount of superphosphate, one value suggested that the residue was more effective than a new dressing.) For potatoes grown in 1960 the residues of the 1959 dressing were only about

TABLE 10

The residual values of single dressings of superphosphate applied in 1959 at 1·0 cwt. P_2O_5/acre for crops grown in 1960 (data are cwt./acre of new P_2O_5 required to give the same yields as the residues in the soil)

Manuring and rotation treatment in old experiment		Barley	Potatoes	Sugar beet
None	Clover	0·8	0·5	0·9
	Fallow	1·5	0·4	0·6
PK	Clover	0·4	0·4	0·4

half as effective (relative to a new dressing) as for the other two crops. Potatoes differ from other crops in ability to use old residues of P fertilisers that have accumulated in soil. This effect has also been demonstrated in work on the very old residues on the Exhaustion Land. The 1960 experiments on Agdell show that it also occurs with 1-year-old residues in the highly responsive soils of the " unmanured " plots. The soil of the clover section of the PK plot of the old Rotation Experiment has a higher P status (barley and sugar beet gave smaller responses to new P), and estimates for all crops were that the residues were equal to broadcasting a new dressing of 0·4 cwt. P_2O_5/acre. Therefore, for barley and sugar beet grown on the richer soil, 1-year-old residues were only half as effective as residues in the poorer soils, but the residues had the same value for potatoes on all three soils.

The results of the new micro-plot experiments on Agdell in 1959 and 1960 showed several differences from the results of comparable work on the Exhaustion Land in 1957 and 1958. On each experimental field the increases in yields given by fresh P fertilisers differ in the two years; this effect was greater on Agdell, where there was the extreme behaviour of sugar beet not responding to new superphosphate in 1959 on a very P-deficient soil, but a large response (nearly 6 tons of roots/acre) in 1960. On the Exhaustion Land, but not on Agdell, a single broadcast dressing of fresh superphosphate (1·0 cwt. P_2O_5/acre) increased the yields of crops on the P-deficient

soils to the same levels as those obtained on soils enriched with fertiliser residues and which had received the same amount of new superphosphate. Another difference between the two sets of results was in the response curves to new phosphate. On the Exhaustion Land superphosphate supplying 1·0 cwt. P_2O_5/acre was adequate for all crops on P-deficient soils. On Agdell, however, some of the response curves in 1959 were linear up to the highest amount of P fertiliser tested (1·0 cwt. P_2O_5/acre). In 1960 the highest rate used on Agdell was 1·5 cwt. P_2O_5/acre, and some of the response curves still did not show a maximum.

The Agdell soil is much heavier than the Exhaustion Land soil, and this, by making broadcast fertiliser less accessible to plant roots, may be partly responsible for the differences in the results on the two fields. The very high values of the 1-year-old P fertiliser residues (in terms of new dressings) for barley and sugar beet on Agdell in 1960 are partly explained by the new dressings of P fertiliser being relatively ineffective. The conventional method of broadcasting new fertilisers is probably not satisfactory for providing P response curves that will evaluate fertiliser residues in the soil, and different methods of incorporating P fertilisers are therefore now being compared. Broadcast dressings of K fertilisers may also be unreliable, even when used as a basal manure, with crops needing much K. In the new experiments with P fertilisers planned for 1961 part of the basal dressing of K is being ploughed in, and the remainder will be applied during seedbed preparation.

Continuous Wheat and Barley sites on Stackyard Field, Woburn

A 2-year programme of micro-plot experiments was begun to measure the value of the residues of P and K fertilisers left in the soil from dressings given annually between 1877 and 1927 to the Classical Wheat and Barley Experiments. The test treatments and basal manuring were similar to those used on Agdell, but only barley and potatoes were grown. The 1960 results gave two estimates for each crop of the separate effects of the P and K residues. The first estimate was made by comparing yields on the plots of the old experiments after applying a basal fertiliser (NK in testing P residues, and NP for testing K residues). In the old experiments each treatment had only a single plot, the old manuring schemes were identical for the barley and the wheat sites except for differences in occasional light dressings of lime on a few subplots; as the two sites have been cropped and manured (with N only) in the same way since 1954, there are pairs of plots with identical manuring history for each treatment. In 1960 the plots that have residues of P fertilisers gave 6 cwt./acre more barley than the old unmanured plots, but less than 1 ton/acre more potatoes. The residues of K fertilisers had much smaller effects on barley than the P residues; on the site of the old Wheat Experiment there was no increase in yield. K residues increased yields of potatoes by 3 tons/acre.

The second estimate of the value of P and of K residues in the soils was derived from the yield-response curves obtained with new dressings of P and K fertilisers. For each crop, and each nutrient, this second estimate is higher than the first. This difference is because new fertiliser dressings did not increase yields on the old

unmanured plots to the level of yields obtained where the same new dressings of fertilisers had been given to old fertiliser plots; as in the Agdell Experiment, this may be because " adequate " amounts of nutrients applied broadcast when making the seedbed are less effective than nutrients distributed through the whole soil. (Warren, Johnston and Penny.)

Analyses of Soils Buried under a Roman Earthwork

Samples were taken in 1959 from soil buried under a Roman earthwork on the Chalk at Winterslow, near Salisbury. The site was excavated by the Ministry of Works. The mound was porous and very calcareous (75% $CaCO_3$); the buried soil underneath was well drained and aerated. Contents of $CaCO_3$, total K and exchangeable K were the same in the buried soil and in the surrounding field. Total N and C and organic P were only one-third as much in the buried as in the surface soil. If the C and N contents of the buried soil were about the same when the earthwork was built as they are now in the surface soil, approximately 60–70% of the C, N and organic P has been mineralised in 1,500 years. Much of the mineralised organic P has been retained by the buried soil as inorganic P soluble in 0·5*M*-$NaHCO_3$. Similar changes may occur when well-aerated soils on the Chalk are cultivated. These soils contain much P, perhaps partly because inorganic P, derived from the decomposition of organic matter, is adsorbed on the surface of $CaCO_3$. (Mattingly and Williams.)

Magnesium

Magnesium in basic slags

As the nutritional disorder in ruminants called hypomagnesaemia may be related to the Mg contents of soils and crops, and because basic slag is widely used on grassland, the value of the Mg in a few slags was investigated in greenhouse experiments with perennial ryegrass. Four sandy loams having the following characters were used:

pH	Exchangeable Mg * (m. eq./100 g.)
4·0	0·07
5·1	0·26
6·8	0·37
7·4	0·14

* In *N*-ammonium acetate.

Two Open-Hearth slags and one Bessemer-process slag were used, they contained:

	No.	Total Ca (%)	Total Mg (%)	Mg soluble in 1% citric acid (%)
Process				
Open-Hearth ...	1	31	5·4	44
	2	27	5·9	31
Bessemer	3	33	1·2	55

The experiments tested three levels of $MgSO_4$ as standard; there was also a test of three levels of $CaCO_3$ to value the liming effect of the basic slags.

Magnesium-deficiency symptoms on the grass were most severe with the very acid soil; they were unaffected by $CaCO_3$ dressings or by Bessemer slag, but the grass was normal where $MgSO_4$ or Open-Hearth slags were applied. Slight symptoms of Mg-deficiency on the alkaline soil appeared after the first cutting where no Mg had been given. All the sources of Mg had only small effects on yield of grass with all soils except the very acid one, with which all Mg treatments increased yield and slag 1 was superior to slag 2 in one experiment; on this soil Bessemer slag also gave much lower yields than the two Open-Hearth slags. The amounts of Mg in the crops were measured by A. Weir (Pedology Department). Magnesium uptakes were compared in pots with slags and in those where liming had given the same pH values. The following results are averages of three experiments with the very acid soil and one with each of the other soils. The second Open-Hearth slag was superior

Percentage "magnesium sulphate equivalents" for two basic slags (amounts of Mg (given as $MgSO_4$) that would have given the same Mg uptake as the basic slags, expressed as % of total Mg supplied by the slag)

	Cut 1	Cut 2
Slag 1	23	23
Slag 2	40	54

in all experiments, and continued to release Mg as the experiment progressed; slag 1 did not release more Mg after the first cut with the acid soils, but uptake by grass on the alkaline soil continued. The uptake of Mg decreased with increasing Ca levels in the soils of pH 5·1 and 6·8 and for the lower level of Ca on the alkaline soil. Increasing the $CaCO_3$ level (up to 8 cwt./acre) of the very acid soil increased Mg uptake during several cuts; with more $CaCO_3$, which raised soil pH to 4·9, Mg uptakes did not alter further. Part at least of the Mg in basic slags is clearly available to grass. Where dressings of 5–10 cwt./acre of Open-Hearth slags of the kinds tested are applied, 25–50 lb./acre of Mg will also be supplied; even if only a proportion of this Mg is available, as in these experiments, it may have a worthwhile effect on crops grown on Mg-deficient soils. No general advice can be given without much more work, because, even for slags of similar Mg contents, the value of the Mg to crops varies for unexplained reasons; Ca–Mg interactions, such as were demonstrated here, will also affect Mg uptake. (Heintze.)

Magnesium in soils

Little of general use is known of the Mg status of British soils, but reports of Mg-deficiency in crops on certain soil types are common. Information is needed on factors that govern the supply of Mg to crops and on the need for Mg fertilisers. Work has begun, in parallel with existing work on soil K, to determine the nature, importance and properties of fractions of soil Mg. (Salmon and Arnold.)

The effect of nitrogen fertilisers on magnesium contents of grass

In a field experiment at Woburn in 1959 ammonium sulphate and sodium nitrate were supplied at 1·0 cwt. N/acre and tested without Mg and with magnesium sulphate supplying 93 lb. Mg/acre. The grass had the following Mg contents:

	Without Mg to grass	With Mg manuring
	% of Mg in dry matter	
Without nitrogen	0·101	—
With ammonium sulphate	0·146	0·209
With sodium nitrate	0·164	0·209

The amount and form of N manuring can obviously greatly affect the Mg content of grass, but much more work is required to establish general principles. (Nowakowski and Otter.)

Molybdenum

The 1959 lucerne of the Ley–Arable Experiment on Highfield contained only 0·1 p.p.m. of Mo (*Rep. Rothamst. exp. Sta.* for 1959, p. 56). In 1960 strips of the 2-year-old lucerne in both the Highfield and the Fosters Field Experiments were sprayed three times with sodium molybdate at 4 oz./acre; the first spray was when the crop was half-grown before the first cut, and the second and third were immediately after the first and second cuts. Table 11 gives analyses of the cuts. (Mo was not determined in the first cut as there

Table 11

Amounts of Mo, N, P and K in dry matter of lucerne from the Rothamsted Ley–Arable Experiments

	Mo (p.p.m.)	N %	P %	K %
Highfield Experiment				
First cut −Mo ...	—	3·14	—	—
First cut +Mo ...	—	3·38	—	—
Second cut −Mo ...	0·01	3·07	0·35	2·28
Second cut +Mo ...	0·40	3·07	0·36	2·26
Third cut −Mo ...	0·03	2·80	0·31	1·72
Third cut +Mo ...	0·29	2·87	0·30	1·88
Fosters Field Experiment				
First cut −Mo ...	—	3·19	—	—
First cut +Mo ...	—	3·36	—	—
Second cut −Mo ...	0·24	2·94	0·36	2·20
Second cut +Mo ...	1·05	2·95	0·37	2·20
Third cut −Mo ...	0·32	2·71	0·32	1·86
Third cut +Mo ...	1·88	2·85	0·31	1·93

was risk of contamination by the spray, N determinations for this cut were on the uppermost growth; the lowest growth was excluded in samples from the second and third cuts.) The sprayed and unsprayed lucerne looked alike, and yields were not increased by the sprays. Mo contents of lucerne on unsprayed plots on Highfield were even lower (0·01 and 0·03 p.p.m. Mo) than in 1959. Applying

sodium molybdate increased Mo to 0·3–0·4 p.p.m.; this did not affect N, P and K contents of the lucerne, which were normal and similar to values for lucerne in the Fosters Field experiment, where the levels of Mo were much higher. The very low Mo content of untreated lucerne on Highfield had not affected N fixation. (Warren, Johnston and Foale.)

Analytical Work

Natural radioactivity in soils

A scintillation counter for the assay of the natural β- and γ-radioactivity in soils was designed and made in collaboration with B. Edwards (Workshop). The counter consists of two parts: (*a*) The sample holder, which can receive 100–300 g. of dry soil, has an interchangeable face so that it can be used with different solid phosphors; (*b*) the photo-multiplier tube assembly incorporates a 5-inch diameter EMI 9530B photomultiplier tube with associated voltage distribution circuitry and cathode follower unit. The whole assembly is housed in a deep-freeze unit at 0°. (Talibudeen.)

Determining carbon in aqueous extracts of soil organic matter

A method for determining carbon in acid or alkaline extracts of soil organic matter without preliminary concentration was developed. The solution is adjusted to pH 4, boiled to drive off absorbed CO_2 and cooled; excess sodium persulphate is added and the solution boiled. The evolved gases are bubbled through saturated KI solution to remove halogens, over hot CuO to oxidise CO to CO_2, dried over $MgClO_4$, and CO_2 is determined gravimetrically by absorbing in soda-lime. The organic carbon in *N*-HCl : *N*-HF extracts of soil can be determined by this method, even when they contain only 50 mg. organic carbon/litre. (Jenkinson.)

Measuring low phosphate concentrations in the presence of much electrolyte

Colorimetric methods for measuring phosphate in the range 0·04–4·0 p.p.m. P are very insensitive when *M*-KCl solutions are used. A method of using Cl'-saturated anion exchange resin and standard ^{32}P-labelled phosphate solutions containing *M*-KCl was developed to overcome this difficulty. The solutions were shaken with resin for varying times and at different resin : solution ratios. The fractional activity in solution under the conditions tested was a linear function of: (*a*) log of phosphate concentration; (*b*) log of time of shaking; and (*c*) resin : solution ratio. The relationship between the fractional activity left in solution and the *initial* phosphate concentration was steeper with smaller reaction times. Resin : solution separation is instantaneous, so the method is simple and rapid, and its accuracy depends only on the accuracy of reproducing the weight of wet resin. The resin : solution ratio used at present is 800 mg. wet resin : 100 ml. *M*-KCl containing between 0·04 and 4·0 p.p.m. of P. By decreasing the resin : solution ratio and the time of shaking, phosphate concentrations $<0{\cdot}01$ p.p.m. can be measured

in the presence of other electrolytes. The method could be used to determine isotopically exchangeable forms of phosphate in solution when they are mixed with soluble non-exchangeable forms that are hydrolysed by the acid treatment necessary in colorimetric measurements. The method could also be used to assay ions of other elements for which there are suitable radio-isotopes. (Vaidyanathan and Talibudeen.)

PEDOLOGY DEPARTMENT

A. Muir

R. Greene-Kelly attended the 3rd Surface Activity Congress at Cologne, the 9th National Clay Conference at Purdue University and the autumn meeting of the Swedish Society for Clay Research at Stockholm. The last two were attended by invitation of the societies concerned. G. Brown and J. H. Rayner attended the International Crystallographic Congress in Cambridge.

A. H. Weir and Ng Siew Kee were awarded the degree of Ph.D. by London University.

Dr. M. Covadonga Rodriguez Pascual of the Instituto de Edafologia y Fisiologia Vegetal, Granada, is working with R. Greene-Kelly on the specific surface of soils. Various other workers spent short periods in the department learning special techniques.

Rock Weathering and Soil Formation

The mineralogical and micromorphological studies of red and yellow latosolic soils from Mount Zomba, Nyasaland, have been substantially completed. These soils belong to the group of " high-altitude soils " in Nyasaland (Young, 1960, *Preliminary soil map of Nyasaland*. Government Printer, Zomba), the main characteristics of which are dark-brown to black top-soils of high humus content overlying yellowish red, fine-textured but friable, strongly acid subsoils of moderate thickness on granite and syenite. Such soils occur at elevations of 5,000–9,000 feet under a wet climate, and are also extensive on Nyika plateau, High Vipja and the Mlanje mountains. Gibbsite, the dominant mineral in the Zomba soils, appears to be derived entirely from the breakdown of the alkali feldspars, orthoclase and sodic plagioclase. A close parallel apparently exists between the type of weathering at Zomba and at Mlanje, where, on the Lichenya plateau, the hornblende–syenite is overlain by a quartzose bauxitic capping (Dixey, *Miner. Mag.* 1925, **33**, 201–5), and the other occurrences of the " high-altitude soils " are probably of a comparable strongly weathered nature. At Zomba these soils in general range from red to yellow latosols and are well drained, but locally in depressions seepage water has led to the development of humic gley soils, which occasionally closely resemble peaty podzolic soils in character. It is intended to extend the work in the area to compare the well-drained latosols with their poorly drained associates. (Stephen.)

Micropedology

The construction by G. C. Dibley of a machine that cuts slices of rock and suitable impregnated soil specimens to approximately 1 mm. thick has greatly decreased the time taken to prepare thin sections. Sections from peds of some surface soils from experimental

plots at Rothamsted and Woburn, both in the undisturbed state and after comminution and deep freezing, were prepared and examined in connection with work being done in the Chemistry Department on pore-space, size and distribution.

Thin sections made from some Russian podzolic soil profiles showed that sandy podzolic soils had a micromorphology similar to that of the iron or iron–humus podzol as defined by Kubiëna, whereas the podzolic soils on heavier textured materials were related to sols lessivés. (Stephen, Osmond and Bullock.)

Mineralogy

Heavy mineral analyses

The " heavy residues " from some soils and sedimentary deposits were studied in connection with field problems encountered by members of the Soil Survey staff. The materials examined include shallow, brown, flinty, calcareous soils of silty clay or silty clay-loam texture on chalk in Hampshire and Yorkshire. The suite of minerals in these soils bears a general resemblance to the assemblages found to be characteristic of loesslike deposits in southern England. Reading Beds and Lower Greensand deposits in Hertfordshire and Essex were also studied to determine their possible contribution to the glacial gravels of the area.

The composition of the very fine sands of a profile from Broadbalk Wilderness Meadow (Soil Survey No. Ht. 38) was studied in detail. The soil has been classed as a Winchester (shallow Batcombe) silt loam. Previous studies of Batcombe and Winchester profiles from the Chilterns showed that the parent material is non-uniform with less-weathered material, presumably of loessial origin, in the surface horizons (Loveday, 1958, Ph.D. thesis, Lond. Univ.; Avery *et al.*, *J. Soil Sci.* 1959, **10**, 177–95). Similarly, in the Broadbalk soil the presence of more than one type of parent material is suggested by the mineralogical data—feldspar being more prominent in the solum above 16 inches than in the basal layer (Table 1). This is shown in both size-fractions examined, but is more pronounced in the 0·08–0·05-mm. grade. Whether the added material is of loessial character cannot be determined, of course, from mineralogical evidence alone, but would require detailed particle-size distribution studies. One point of interest, however, is that heavy residues rarely contain garnet, a mineral previously found to be characteristic of the silty surface horizons of Batcombe and Winchester profiles in other parts of the Chilterns.

The presence of appreciable amounts of andalusite throughout the Broadbalk profile is noteworthy. Previous studies of subsoil horizons of Batcombe and Winchester profiles show their heavy mineral suites to be closely correlated with those of Reading Beds—zircon, tourmaline, rutile, staurolite and kyanite constituting the bulk of the separates (Table 1, A and B). In materials examined by Wooldridge and Ewing andalusite never exceeded 0·5% in Reading Beds, but was characteristic of Pliocene deposits (now considered as early Pleistocene), accompanied by monazite and green spinel (Table 1, C). Monazite occurs in small amounts throughout profile Ht. 38, but green spinel has not been observed. Nevertheless, the

large differences in amount of andalusite compared with other Batcombe and Winchester profiles merit consideration of a possible Pleistocene origin for much of the material constituting the profile. It is of considerable interest in this connection that ferruginous sandstone of Red Crag age was described by Dines and Chatwin (*Summ. Progr. geol. Surv. Lond.* 1929, pt. III, 1–7) among material

TABLE 1

Mineral Distribution

	Profile Ht. 38						
	1–5 in.	6–10 in.	12–16 in.	30 in.+	A	B	C
Feldspar in light separates, %							
0·1–0·08 mm. ...	2	3	1½	½–1			
0·08–0·05 mm. ...	10	8	10	3			
Heavy minerals (0·1–0·08 mm.), %							
Zircon	36	37	22	20	51½	36½	53
Tourmaline ...	26	32	32	41	22½	38	12½
Rutile	14	13	14	9	9	5½	10½
Garnet	—	—	1	—	—	—	—
Staurolite ...	10	9	8	11	8	15½	8
Kyanite	5	3	7	7	3	4½	9
Andalusite ...	6	4	9	9	—	—	7

Note: Only the most commonly occurring heavy minerals are listed. A, average of numerous samples, Reading Beds, Lane End; B, average of samples of Reading Beds from the main outcrop at Batchworth Heath, Sandy Lodge and Watford Heath; C, average of high-level Pliocene deposits, Little Heath and Lane End. (Wooldridge and Ewing, *Quart. J. geol. Soc. Lond.* 1935, **91**, 293–317.)

from a trench running from north-east to south-west across West Barnfield, and fragments of the sandstone were also found on Sawyers and along the western boundary of Long Hoos. (Stephen.)

Rectorite and allevardite

Three samples of allevardite, from Allevard, France, from Baluchistan and from Dagestan, Caucasus, the last kindly given to us by Dr. Kotelnikov, Institute of Geology and Exploitation of Caustobiolites, U.S.S.R., were compared with a sample of rectorite from Arkansas (U.S.N.M. 80607). Extensive X-ray-diffraction studies show that all give very similar patterns under a variety of conditions and treatments. The morphology shown by electron microscopy and chemical composition are also similar. This work suggests that the names rectorite and allevardite are synonymous, rectorite having priority.

Ivkin, Kitaigorodsky, Kotelnikov, and Korolev (*Mem. All-Union Miner. Soc.* 1959, **88**, 554–563) in their description of the Dagestan material index 00*l* reflections on the basis of a superlattice of period 4 × 25 Å. for the air dry material. Drs. Korolev and Kotelnikov informed us that they found a basal reflection of 50 Å. spacing from both Dagestan and Baluchistan allevardites and also sent their patterns, showing this reflection, which had been taken with filtered radiation. We had not observed this reflection with our cameras.

Examination of the allevardites and rectorite with crystal-reflected radiation, with an experimental arrangement capable of recording spacings up to 80 Å., also failed to show any trace of this reflection, which must therefore be attributed to "white" radiation. The other superlattice reflections which they observe can probably be attributed to:

(i) The simultaneous presence of more than one hydrate leading to more than one set of 00*l* reflections.

(ii) Impurities. For example, Baluchistan allevardite often contains small quantities of mica with a 10 Å. basal spacing, and a chlorite impurity with a 14 Å. basal spacing is unevenly distributed in our sample of Dagestan allevardite. (Brown and Weir.)

Clay mineralogy

The following samples were analysed for clay minerals. For the Soil Survey of England and Wales 128 samples, for the Colonial Office 36 samples from Borneo and 107 specimens of soil clays, minerals and other materials from Britain and overseas. Of the 271 samples, 247 were analysed for clay minerals.

Red and brown soils from Borneo show marked differences in their clay mineral content, which are to some extent linked with the parent materials. Thus, soils on sandstone and shales show dominant mica in the clay, whereas one soil on basalt showed dominant kaolin, another on basalt colluvium showed dominant vermiculite. The alluvial and coastal soils from Malaya are variable in their clay minerals: a very acid coastal plain soil from Kedah contained mainly montmorillonite; an alluvial soil from Selangor was mainly kaolin, as was another from North Kelantan. The alluvial soils from Borneo all had a high clay mica content.

Work on the Old Red Sandstone sediments from the West Midlands was delayed by other work, and has not proceeded as quickly as we would have liked, but forty-seven samples from our collection were examined. (Du Feu and Brown.)

Physical Chemistry of Soil Minerals

Optical properties of clays

The work described in last year's Report was continued, and the validity of the current method of determining the optical constants of clay aggregates was examined. This method consists of immersing aggregates in non-penetrating mixtures of liquids of differing refractive indices and determining the point of minimum relief. The assumption that the solid index equals the liquid index at minimum relief is valid only when there is no form factor. Usually the indices determined are not the true ones, and their difference, that is the birefringence, bears little relation to the correct value. The possibility of using penetrating liquids, and compensating for any form factor, is being studied.

The relation was established between the difference in birefringence when a dry montmorillonite aggregate is complexed and the polarisabilities of the intercalated molecules. More detailed

study showed small differences that must be due to changes in the molecular polarisabilities on sorption. (Greene-Kelly.)

Surface studies

The specific surfaces of aggregates formed from mixtures of suspensions of clay minerals were measured by nitrogen adsorption, and the results have shed light on the structure of Na-montmorillonite aggregates. It was earlier suggested that these aggregates are composed of a random collection of oriented silicate layers with little or no formation of stable sub-units (e.g., crystals). The conclusion from our experiments is that there are sub-units present.

The calorimetry of clay–water systems, from room down to low temperatures, began, and the freezing and the heat capacity of the sorbed water films will be studied as a function of exchange cation. (Greene-Kelly.)

Hydrothermal synthesis of clay minerals

The main work this year was an examination of the rate of formation of kaolinite from a co-precipitated silica gel. 0·5-g. samples were heated with 1 ml. of water in a gold capsule in a small autoclave sealed with a copper disk. The products were shown by electron microscopy to consist of aggregates of about the same size as the particles of gel used (which had been ground to pass a 300-mesh sieve) and had crystalline laths growing out in all directions. This morphology allowed X-ray-diffraction measurements of the quantity of kaolinite present to be made more accurately than for kaolins containing separate platelets, with which there is always strong preferred orientation in the surface layers of the sample exposed to the X-ray beam. The amount of kaolinite measured in this way was closely correlated with that found by thermogravimetry.

The reaction roughly followed a first-order law, and after a week at 300° was, as far as could be measured, complete. The time taken for half the material to be converted was about 8 hours at 300°, about 1½ days at 260° and about 11 days at 220°. At 180°, conversion of part of the material to kaolinite had just detectably begun after 7 days.

It is hoped that experiments at lower temperatures for longer times will enable the rate of reaction likely at the temperatures found at the earth's surface to be estimated, and that this estimate will not be invalidated by an unknown change in the nature of the reaction occurring below the lowest temperature at which measurements are made. An invalid result would almost certainly be obtained if the extrapolation was made from the present results, as they show some change in the degree of order in the kaolinite crystals formed as the temperature changes from 300° to 220°. (Rayner and Greene-Kelly.)

Spectrochemistry

Further work was done in connection with the danger of poisoning plants by heavy metals contained in sewage sludge contaminated by industrial waste.

The previous work, mainly on sugar beet, drew attention to the

possibility of similar trouble occurring in the Market-garden Experiment at Woburn, in which sewage sludge was used. Extracts from the sludge and from the soils in the plots to which it had been applied indicated an appreciable contamination of the soil by zinc, copper, nickel, chromium and lead. Successive crops of leeks and globe beet grown on these plots were also analysed for these elements. The leeks from the sludge-treated plots contained significantly more zinc, nickel and copper than those on the untreated plots, and the globe beet contained more zinc and nickel.

Sitka spruce seedlings suspected by the Forestry Commission to be stunted and discoloured because of the heavy metals were analysed, but the suspicion was not confirmed. Many other spectrographic examinations were made, both for workers at Rothamsted and elsewhere, including trace-element surveys of soils from North Borneo and St. Helena for the Colonial Office. Consultative work of this kind occupied most of one worker's time throughout the year.

Work on the general levels of trace elements in the soils of southern England include attempts to identify constituents of the soils with which the various elements are associated.

The brown and grey forms of London Clay were compared to ascertain why the grey clay weathers brown at and near the surface more than do some other sedimentary deposits. Specimens traversing the brown to grey transition in a quarry near Workingham were examined. The most notable differences lay in their contents of FeS_2 and $CaSO_4$ (0·03–0·1% of both in the brown compared with 0·5–0·7% FeS_2 and 0·3% $CaSO_4$ in the grey). The grey also contained more $CaCO_3$ and organic carbon, but the difference was not as great. These London Clays differ strikingly from the Lower Lias shales in their contents of $CaCO_3$, organic C and FeS_2. Whereas average values for these in the grey London Clay were 3, 0·4 and 0·6% respectively, corresponding values for a typical Lower Lias shale were 30, 8 and 6%. These figures, indicating a much more reduced environment in the Lias, seem to offer an adequate explanation for the greater ease of oxidation of the London Clay. Added to this is the fact that at the site where these specimens were taken the material is much sandier (about 50% > 20 μ) than the Lias, making it relatively porous and thus weatherable to a greater depth. Further evidence that leaching readily occurs is provided by the lower concentrations of $CaSO_4$ oxidisable FeS_2 and organic matter in the brown than in the grey clay. (Le Riche and Burnett.)

Equipment for the direct-reading spectrographic-determination of magnesium was made and is now under test. (Weir.)

Soil Chemistry

Effect of soil waterlogging

Molybdenum co-precipitated with ferric oxide is mobilised by the action of anaerobically decomposing plant material, but the ferrous iron formed causes the pH of the mixture to rise, so solution of Mo could result simply from greater solubility of molybdate at alkaline reactions. However, adding plant material to a soil before incubation increases the amount of Mo extracted by either water or neutral or acid ammonium acetate, although the pH of the

reaction mixture is consistently lower in the presence of added plant matter. In a typical example, the water-soluble Mo in a soil was increased approximately eight times by incubation with dried grass, although the pH of the reaction mixture remained almost constant at 5·3, so the mobilisation of Mo in poorly drained soils is clearly not merely a pH effect.

Mo dissolved from ferric oxide co-precipitates by fermenting plant material is readily co-precipitated with ferric oxide when the fermentation solution is exposed to the atmosphere; this suggests that the Mo persists in its original anionic form throughout the fermentation. This also appears to be true for vanadium. The order of ease of co-precipitation of minor elements with ferric oxide obtained was Mo, V > Sn, Pb > Zn > Cu > Co, Ni, Mn, which agrees with the evidence provided by analyses of ironstone and lateritic concretionary materials.

It was reported previously that Cu is irreversibly sorbed by the fibrous constituents of undecomposed plant material. Ni, Pb and Zn behave similarly, and Co and Mn are fixed to a much smaller extent. This fixation suggests a parallel with the low availability of Cu in many organic soils, which causes "reclamation sickness" on fenlands. An attempt was made to see how far the fixation by peat results from "humification", and how far it is a persistent property of the original plant material. Weight for weight of oven-dry ash-free material, phragmites peat fixes much more Cu or Ni than fresh phragmites fibre, and the fixing capacity of peat is considerably reduced after removing humified material by a mild reagent such as neutral ammonium oxalate. Removal of pectins decreases the fixing capacity of the fresh fibre, so it is apparent that, although one potential fixing agent, i.e., pectin, is destroyed during peat formation, humification involves the formation of compounds that can also fix relatively large amounts of Cu, etc. Removal of benzene-soluble material or protein from both peat and phragmites fibre increases the fixing capacity of the residue, so that these experiments give no indication of the extent to which these constituents contribute to the fixing properties of the original materials. The increased fixing capacity of the benzene-extracted material is probably largely a result of the less hydrophobic nature of the product, but it seems unlikely that proteins would not contribute to the fixation of Cu for example; removing protein thus appears to expose more reactive sites on the lignin-cellulose residues. (Bloomfield, Ng Siew Kee, Greet and Pruden.)

A method for determining total sulphur in soils is required in connection with a projected study of the reduction of sulphate in waterlogged soils. A procedure involving igniting the soil in a quartz tube in the presence of V_2O_5 was developed, and shows promise of providing a rapid and accurate method for determining total sulphur. The sulphur is evolved as SO_3, which is collected in dilute hydrogen peroxide; the resulting sulphuric acid can then be determined titrimetrically. (Bloomfield.)

An experimental approach, used to find out how calcium carbonate is removed, moved or accumulated as a calcareous horizon in soil profiles, showed that $CaCO_3$ can be leached quite readily out of columns of siliceous sand that are percolated with CO_2–water.

When the partial pressure of CO_2 in the water is reduced to a level at equilibrium with laboratory air, a small amount of calcium carbonate is removed initially, but the bulk is unaffected. Carbonate was always removed from the top rather than from the layer as a whole. When tap water, containing about 0·4 g./litre of dissolved solids, is percolated through the columns there is partial removal of solids as the water passes through a calcium carbonate layer. (Wells.)

SOIL MICROBIOLOGY DEPARTMENT

P. S. Nutman

J. Meiklejohn was awarded a Research Fellowship tenable at University College, Ghana, where she spent six months working on the microbiology of the nitrogen cycle in forest and grassland soils. J. Kleczkowska worked for three months at the Microbiology Laboratory, Wageningen University, on the effects of phage lysates and bacterial extracts of *Rhizobium trifolii* on growth and symbiosis. B. Mosse came in March on a two-year secondment from East Malling Research Station to work on endotrophic mycorrhiza. J. Darbyshire, formerly of Matopos Research Station, Southern Rhodesia, came in November for post-graduate research training. B. M. Gupta returned to Lucknow in November. Prof. D. C. Jordan (Ontario Agricultural College) and H. Ljunggren (Agricultural College, Uppsala) worked in the department during the year.

Except for the work on mycorrhiza, no entirely new research was initiated. The programme on nitrogen metabolism in nodules and on fixation was extended by the use of ^{15}N. Ecological studies were enlarged by the work on tropical soil, by developments of the *Azotobacter* inoculation work and by minor field investigations on the distribution of *Rhizobium* and of aerobic cellulose decomposers. The work on decomposition of chemicals in soil and on clover genetics was decreased and will not be reported on.

Genetics of Rhizobium

Seventy-one mutant strains of *Rh. trifolii* (strain A121111, effective on red clover), obtained after various selective procedures, were examined for their nutritional requirements, phage and streptomycin resistance, serological type and symbiotic effectiveness. Using an auxanographic technique (which also estimated biotin and thiamin excreted by the host root) the vitamin, amino-acid and nucleic acid requirements were determined. The only nutritional mutant found was a strain not requiring thiamin, obtained after exposure to ultraviolet irradiation.

Of 51 mutants obtained by ultraviolet and streptomycin treatment, only three were ineffective in fixing nitrogen, and none was phage-resistant or serologically changed.

Phage differed from the other selective or mutagenic agents in that a high proportion of the resistant mutants also differed from the parent strain in symbiotic properties. Thus of 14 stable phage-resistant mutants 13 were ineffective in nitrogen fixation with red clover. Six other resistant and ineffective mutants, which soon reverted to susceptibility in absence of phage, also tended to revert to effectiveness; one remained ineffective, two gave mixed responses and three regained complete effectiveness.

This association between the appearance of phage resistance and

ineffectiveness confirms work previously reported for other strains (*Rep. Rothamst. exp. Sta.* for 1958) and is being further investigated by transformation studies. The rates of mutation to phage resistance and streptomycin resistances were calculated. (Kleczkowska and B. M. Gupta.)

Polygalacturonase and cross-inoculation-group specificity

Fåhraeus and Ljunggren (*Physiol. Plant.* 1959; *Nature, Lond.* 1959) showed that polygalacturonase (P.G.) is produced in the rhizospheres of clover and lucerne plants in the presence of bacteria able to infect them. Neither bacteria nor host alone, or incompatible combinations of host and bacteria, produce P.G., but polysaccharide extract from compatible bacteria induces its production by the host.

The relation between cross-inoculation group specificity and P.G. production was further examined during Ljunggren's visit to this Department, with eight host species belonging to four cross-inoculation groups and an appropriate collection of strains of bacteria. P.G. was detected only when the plant was inoculated with a bacterium to which it was susceptible.

Measurements of the enzyme produced by plants carrying different numbers of nodules showed that P.G. production was highly correlated with actual nodule formation in red and in subterranean clover, whether abundantly or sparsely nodulating strains of bacteria or selections of host were compared. Polysaccharide added to plants inoculated with virulent strains promoted earlier nodule formation. (Ljunggren.)

Transformation in Rh. trifolii

The avirulent mutant (Strain Bart. A) of *Rh. trifolii* produced no P.G. Virulence and competence to induce P.G. were restored to this strain by treating it with a bacteria-free preparation of the polysaccharide of a virulent (unrelated) strain in the presence of the host root. The nodules so produced were effective in nitrogen-fixation, and isolates from them retained their virulence without any added polysaccharide. Serological tests showed that the transformed strain did not have the specific polysaccharide of the parent virulent strain from which Bart. A. was derived.

These results point to a solution of the long-standing problem of cross-inoculation group-specificity, for variations in composition and structure of bacterial polysaccharide give ample scope for the complex pattern of cross-inoculation specificity which has been described.

Very little P.G. is produced, and the mechanism of its activity in the infection process is not yet understood; it may dissolve the primary wall locally or be released as a result of synthetic processes associated with primary wall growth; and if the infection thread is formed by invagination it may also aid this process. (Ljunggren.)

Clover-root hair infection in agar and in soil

The effect of various densities of rhizosphere population of rhizobia on infection was studied. To vary the number of bacteria in the inoculum, a virulent strain (A121111) was mixed with an

avirulent mutant (Bart. A.) in various proportions and a large total inoculum used (as in *Ann. Bot.* 1957). This minimised multiplication of the bacteria and kept the density of the virulent component near to the original numbers added.

The density of rhizobia required to initiate infection varied with different host species; the increase in density needed for every additional infection then remained constant and did not differ much between species till a nodule or nodules formed, when the number of bacteria necessary for further infection increased several fold.

In two contrasting soil types, (*a*) Rothamsted heavy clay soil and (*b*) Woburn light loam soil, infection proceeded at the same rate. In both soils fewer infections were observed than on agar, though the population size of nodule bacteria in the rhizosphere was high enough (between 10^4 and 10^8 per rhizosphere) to warrant more infections than were observed. The bacteria from the soils were later shown to have normal infective virulence. Studies on the effect of some root-surface fungi on infection showed that bacterial density was not the only controlling factor. This work was done in soft agar with washed spores of the fungus added, together with a rhizobium inoculum of known size. Some fungal species regularly stimulated infection, whereas others either had no effect or decreased infections. None of these fungi affected the size of rhizosphere population of nodule bacteria. (G. Lim.)

Nodule formation requires substances elaborated in the top of the plant, and cutting off the top stops nodulation: if the top is replaced by an artificial source of carbohydrates, vitamins, etc., nodule formation continues only briefly and sparsely. (Raggio, *Amer. J. Bot.* 1957.)

The effect of top excision on root-hair infection, as distinct from nodule formation, was examined in several species of host, which were cut and inoculated when 3–6 days old, before infection of intact plants normally begins. Roots of *Trifolium fragiferum*, *T. repens* and *T. glomeratum* without tops contracted about as many infections as did those with tops, whereas removing the tops of *T. parviflorum*, *T. scabrum* and *T. nigrescens* greatly decreased infections. In all species, excision changed the distribution of infected hairs along the root by making the zonation of infection in intact plants less evident and by regularly increasing the density of infections towards the root tip. It is hoped that further work will explain the normal pattern in which infection is initiated at a few separated centres that enlarge as the seedling develops. Whole seedlings are infected in two exponential phases; the end of the first, more rapid, phase coincides with nodule formation. The effect of nodules on infection was examined in experiments in which nodulation was delayed by including trace quantities of nitrate nitrogen in the medium (*Rep. Rothamst. exp. Sta.* for 1958, p. 73). This led to more infections than on control plants. (Nutman.)

Failure of trefoil (*Medicago lupulina*) in green manuring experiments at Woburn seems to result from lack of nodule bacteria in the period of early growth of the crop (which was not inoculated). In October (5 months after sowing on Stackyard Series C, and 2 months after sowing on Lansome Field) only an occasional trefoil was fully green and effectively nodulated (mostly by few very large,

fasciated nodules). The remainder were without nodules or poorly nodulated. *Rh. meliloti* was very sparse (< 1 bacteria in 10 g. soil) in plots without trefoil and very irregularly distributed under trefoil, indicating that the small residual population at sowing did not increase soon enough to give uniform effective nodulation. Populations in excess of 10^8/g. rhizosphere soil were found in trefoil sown on the Green Manuring Rotation Experiment, Stackyard field series A, where trefoil has been grown for some years. The need for trefoil inoculation is not well recognised, and some strains of bacteria are being examined as suitable inocula. (Dyke and Nutman.)

The poor establishment of uninoculated white clover on new land at Fritham Plain, Hampshire, was associated with failure of effective nodulation. Watering on of an effective strain gave statistically significant increase in growth. (Scowen.)

Nitrogen metabolism of root nodules

Soyabean nodules were crushed and separated by centrifuging into bacteroids, supernatant fluid and a fraction sedimenting at 30,000 X g., probably containing the membranes which enclose packets of bacteroids in intact nodules. All three fractions actively synthesised glutamine from added glutamate and ammonia in the presence of adenosine triphosphate. The synthesis per mg. of protein was greater in the supernatant than in the membrane fraction; technical difficulties have so far hindered quantitative estimation of the activity of the bacteroid fraction. (Cooper and Jordan.)

A start was made on a direct study of nitrogen fixation by the ^{15}N technique. An all-glass apparatus was built for making up the necessary atmospheres; this was designed so that oxygen and carbon dioxide can be absorbed, and the $^{15}N_2$ left after incubation used again in later experiments. ^{15}N assays were kindly done by A. C. D. Newman (Chemistry Department). The amount of $^{15}N_2$ taken up by intact, detached nodules from soyabeans increased by 50% when pyruvate was added to the fluid bathing the nodules. After 3 hours' incubation the supernatant fraction contained 10 times more ^{15}N than the bacteroid fraction. Preparations of crushed and filtered nodules incubated with atmospheres containing $^{15}N_2$ were also enriched with significant amounts of ^{15}N, though the uptake has so far been too small for convenient study. Such preparations are potentially more valuable than intact nodules for the study of the mechanism of nitrogen fixation, and further efforts will be made to promote their activity. (Cooper.)

The establishment of mycorrhizal infection under aseptic conditions

The establishment of mycorrhizal infections in aseptic culture is necessary to investigate critically their effect on root metabolism. Typical vesicular–arbuscular infections were established in clover seedlings grown aseptically in test-tubes, on an agar medium, on Fåhraeus slides and in water culture. Successful test plants include *Trifolium parviflorum*, *T. glomeratum*, *T. pratense*, *Dactylis glomeratum*, wheat, cucumber and onion, but no infections developed in four different strains of subterranean clover. Sterile seedlings were grown in an inorganic nutrient medium lacking nitrogen

(Jensen's), and germinated spores of an Endogone species were used as the fungal inoculum. The fungus did not penetrate the roots unless some bacterial contaminant was also present. Two different species, thought to be *Pseudomonas*, were isolated in pure culture; both effectively mediated the changes necessary for root penetration. Neither appears to have any direct effect on growth of the *Endogone* sp. or on the germination of its resting spores. The mechanism of the bacterial effect is being investigated by the use of sterile filtrates, and of autoclaved and sonically disintegrated bacterial suspensions.

Under the above conditions, seedling roots were penetrated 8–12 days after inoculation with fungus and bacterium; temperature and light conditions suitable for normal seedling growth are necessary. Early infections are predominantly arbuscular, and vesicles do not develop abundantly till the seedlings begin to decline after 4–8 weeks growth in a nitrogen-deficient medium. Adding 0·05% of asparagine, urea, sulphate of ammonia or potassium nitrate inhibited root penetration even in the presence of bacteria, but a few test plants became infected after 12 weeks, when acute symptoms of nitrogen deficiency had developed. Once root penetration occurs the external mycelium is greatly stimulated and hyphae begin to grow into the agar. The agar becomes extensively colonised when vesicle production is greatest and the seedlings begin to decline. The fungus could not be subcultured, but produced mycorrhizal infections in fresh seedlings planted on infected agar slopes. Seedlings could also be infected by inoculation with infected roots. (Mosse.)

Infection with either of the two species of bacteria necessary to establish mycorrhizal infection also stimulated growth of the clover and grass seedlings in the nitrogen-deficient medium, even without the *Endogone* sp. Inoculation with bacteria gave darker green seedlings with more vigorous root systems. These seedlings contained more nitrogen than uninoculated controls, and the nitrogen content of the inoculated agar medium decreased. It is concluded that normally inaccessible nitrogen compounds, probably in the agar, were rapidly made available to the plant by the action of a small bacterial inoculum. Further studies are in progress on the mechanism of this action and on the subsequent development of mycorrhizal, bacterial and uninoculated test seedlings transplanted into autoclaved soil. (Mosse and Cooper.)

Mycorrhizal fungi in soil

The spread of mycorrhizal fungi in soil free from host roots was investigated by burying sporocarps of an *Endogone* sp. in an autoclaved soil. The soil layer containing the sporocarps remained infective after 12 months, but there was no evidence that the fungus had spread in the soil. Sporocarps similarly buried together with strawberry roots also failed to produce mycorrhizal infections in apple seedlings. Inoculation with the soil layer which had contained infected strawberry roots considerably depressed growth of the test seedlings. (Mosse.)

Inoculation experiments with Pythium ultimum *and* Endogone *sp.*

An experiment with Dr. L. E. Hawker (Bristol University) designed to compare the incidence and anatomical appearance of mycorrhizal infection after inoculation with a culture of *Pythium ultimum* and with sporocarps of an *Endogone* sp. was repeated. Onion and apple seedlings were used as test plants. Mycorrhizal infections produced by inoculation with *Endogone* sporocarps showed a more extensive development of the external mycelium and of the arbuscular stage than those produced by inoculation with *Pythium*. The relatively high proportion of mycorrhizal infections which developed in the uninoculated control plants makes it difficult to draw any final conclusions, but the differences in anatomical details of the infections strongly suggest that both fungi can sometimes cause vesicular–arbuscular infections in the same host. The viability of sporocarps associated with test plants grown in two different autoclaved soils, a potting soil and a soil from Cleeve (Somerset), differed greatly. Sporocarps which had developed in the Cleeve soil contained very few viable resting spores, whereas those from the potting soil contained 40–90%. This observation may have some bearing on the prevalence of different species as endophytes in different localities.

The growth of the mycorrhizal and non-mycorrhizal seedlings differed greatly, the mean fresh weights of infected plants being two to three times as great. In onion, infection stimulated bulb production. (Mosse.)

Studies on Nitrosomonas

The results of the work on growing *Nitrosomonas* in continuous culture were published (4·6). Much time was spent in trying to improve this method of producing *Nitrosomonas* cells in quantity. The occasional failure of *Nitrosomonas* to grow in the culture apparatus is still puzzling, although it is now clear that efficient aeration is indispensable to successful continuous culture at high cell densities. The use of $NaHCO_3$ instead of Na_2CO_3, or adding CO_2 to the air supply, seem inessential. Preliminary attempts to prepare cell-free extracts able to oxidise NH_3 failed. (Walker and Skinner.)

By the use of Engel and Skallau's dilution technique, but employing a clear medium, two further strains of *Nitrosomonas* were isolated in presumed pure culture. One of these, from a sample of Rhodesian soil that had an unusually high Cu content, was motile. The other, isolated from a lateritic soil from the island of Korcula, at first appeared to be growing as a zooglea, but when isolated in pure culture was a feebly motile strain, somewhat bigger than the stock strain. (Walker.)

Cellulose decomposition and methane formation

Strains of anaerobic cellulose-decomposing bacteria that have been studied digest cellulose slowly and produce organic acids. The Rothamsted strain (*Rep. Rothamst. exp. Sta.* for 1959) forms enough formic and acetic acids to depress the pH of heavily buffered liquid cellulose medium from 7·0 to about 5·0 during fermentation.

In nature, anaerobic cellulose digestion is often associated with the formation of methane and stabilisation of the pH at about 7·0.

Enrichment cultures of two strains of methane-forming bacteria able, respectively, to use formate and acetate as substrates, were prepared and partially purified, but so far it has been impossible to remove the remaining one or two species of bacterial contaminants. Media suitable for growing methane bacteria are not highly selective because the fatty-acid substrates are used by a variety of other micro-organisms. Some degree of selectivity is, however, imposed by the necessarily stringent anaerobic conditions, and by setting the pH initially at 7·0–7·4.

Methane bacteria appear to require for growth only a simple medium containing ammonia, carbonate and the organic substrate in mineral salts solution. A simple and convenient way of preparing this medium makes use of the apparatus designed to prepare and distribute anaerobic media for cellulolytic anaerobes (*Rep. Rothamst. exp. Sta.* for 1957).

The conversion of cellulose to methane was studied by the use of mixed cultures containing cellulose-decomposing and methane-forming bacteria. Mixed cultures were set up in liquid cellulose medium containing a little of the appropriate fatty acid and inoculated with methane formers so that they could become established before the cellulose-decomposing bacteria were introduced. Cellulose was digested with a steady evolution of methane over a period of months. The pH remained constant at about 7·0. Similar cultures without the methane bacteria quickly became acid and evolved little gas. The cellulose was not decomposed more quickly when methane bacteria were present.

A fermentation apparatus designed to grow these anaerobes under controlled conditions and to provide facilities for measuring pH and redox potential without disturbing the cultures is being built. (Skinner.)

At the request of the Sports Turf Research Institute (Bingley, Yorkshire) the appearance of sunken areas on the grass of a Surrey golf course was briefly studied. Sinkage seemed to be caused by bacterial decomposition, and consequent collapse, of a layer of organic matter 10–20 mm. below the soil surface. Recommendations were made to increase the mechanical strength of the organic layers by working sand into them and, in future, to top-dress with a mixture of organic matter and sand. (Skinner.)

Nitrification and nitrogen fixation in West African soils

The bacteria concerned in the nitrogen cycle were counted in Ghana forest and grassland soils. These two types of vegetation produce very different levels of soil fertility. The forest soils are very fertile, with a high content of exchangeable bases, organic matter and nitrogen. Grassland soils are much less fertile, and in particular lack available nitrogen. Jensen and Becking's methods were used to count nitrogen-fixing bacteria and a recently developed method to count nitrifying (ammonia-oxidising and nitrite-oxidising) bacteria.

The forest and grassland soils differ little in their content of nitrogen fixers; the numbers are generally high, and slightly higher

in grassland soils. There are large differences in the numbers of nitrifiers; as long as soil cover is maintained, forest soils contain many ammonia- and nitrite-oxidisers, whereas grassland soils contain few ammonia-oxidisers and very few or no nitrite-oxidisers. It was particularly striking that none of the grassland samples taken after the start of the rainy season (in April) contained any nitrite-oxidisers. (Meiklejohn.)

Azotobacter *and plant growth*

Experiments on the effect of *Azotobacter* inoculation on plant growth continued, primarily with the object of determining the conditions for reproducibility between experiments. The principal

TABLE 1

Crop	Type of experiment	Treatments	% increase (+) or decrease (−) in yield from inoculation
1. Cress	Tube Nutrient agar	Seedling inoculation ± N supplied as KNO_3, $(NH_4)_2SO_4$, KNH_4NO_3 (14 treatments)	+13·0% sig.*
2. Radish	Tube Soil (Broadbalk 3, 2 1b and 7)	Inoculated vermiculite mixed with soil (6 treatments)	− 1·6% n.s. (Soil 3 -21·0% sig.)
3. Radish	Pot Soil (Broadbalk 3, 2 1b and 7)	Soil surface inoculation + nutrient solution. High and low N (12 treatments)	−13·4% n.s.
4. Radish	Pot Soil (Broadbalk 3, 2 1b and 7)	Soil surface inoculation + nutrient solution. High and low N (12 treatments)	−11·5% n.s. (Soil 3. High N + 39·0% sig.)
5. Radish	Pot Potting compost J.I. No. 1 with soil from Great Field 4	Seed and surface inoculation with two Azotobacter strains (6 treatments)	− 4·4% n.s.
6. Radish	Pot Potting compost J.I. No. 1 with soil from Great Field 4	Seed inoculation (2 treatments)	+ 7·4% n.s.
7. Spinach	Pot Soil (Broadbalk 2 1b)	Surface inoculation. N.P.K., $MgSO_4$ and nutrient soil (2 treatments)	+28·5% sig.
8. Barley	Pot Soil (Broadbalk 2 1b)	Surface inoculation N.P.K. factorial and nutrient solution (16 treatments)	+40·1% sig.
9. Barley	Pot Soil (Broadbalk 2 1b)	Surface inoculation with 4 inocula, 3 levels of N (15 treatments)	− 3·47% n.s.
10. Barley	Pot Soil (Broadbalk 2 1b)	Surface inoculation with old and new inocula. N.P.K. + nutrient solution ± Mannitol (M). Moisture 100% and 60% W.H.C. (12 treatments)	− 0·98% n.s. (60% W.H.C. new inoc. − M + 23·7% sig. 60% W.H.C. new inoc. + M + 21·8% sig. 60% W.H.C. old inoc. + M + 23·2% sig.)
11. Spring wheat	Field Waterbeach Fen, Cambs.	Seed inoculation ± N (8 treatments)	− 2·68% n.s. Fresh wt. of grain
12. Spring wheat	Field Garden plots Rothamsted	Soil inoculation. 2 levels of N and no added N (6 treatments)	+ 6·7% n.s. Fresh wt. of grain. (No N plots + 18·0% sig.)
13. Sugar beet	Field Garden plots Rothamsted	Seed inoculation. 2 levels of N and no added N (6 treatments)	− 3·89% n.s. Fresh wt. of beet

* Significant level of probability 5% or less. (Unless otherwise stated figures are calculated from total dry weights of plants.)

factors investigated were the type of inoculum and method of inoculation and the influence of soil type, soil nitrogen level and soil moisture. Two methods of inoculation were used to establish artificially high levels of *Azotobacter* in the plant rhizosphere. In the first, a suspension of cells was applied to the soil after sowing;

in the second, a cell suspension was sprayed with an atomiser on to the seed not more than 24 hours before sowing.

Although the conditions for reproducibility are not yet defined, enough has been done to show that *Azotobacter* inoculation sometimes affects plant growth. Table 1, which summarises all the experiments, shows the total effect of inoculation on plant yield for each experiment, except where significant effects were restricted to certain treatments, which are then shown separately.

No conclusions can yet be drawn about the factors affecting crop response to inoculation; for example, in experiment 8 yield was increased more when combined nitrogen was added, whereas in experiment 12 response to inoculation decreased with increasing applications of nitrogen. Establishment of *Azotobacter* in the rhizosphere was not the limiting factor, because this was achieved in some experiments in which no observable effects on plant growth were obtained. (Jackson, Brown, Burlingham and Barford.)

Methods of counting Azotobacter

In some inoculation experiments bacteria were counted in inoculated and uninoculated rhizospheres. Counts were made by the dilution plating technique and by serial two-fold dilutions with liquid medium, numbers being estimated by counting positive tubes and referring to tables of most probable number. Experiments were also made to improve counting methods and to determine sample variation and the natural distribution of this organism.

Sucrose and glucose in the plating medium gave about twice as many colonies as mannitol. This was not because some strains cannot use mannitol. Small but countable colonies of *Azotobacter* developed on dilution plates which contained no added carbon compounds; colony numbers were similar to those with glucose and sucrose.

The most probable number method gave results comparable with those obtained on dilution plates and saves labour and materials. However, results are sometimes obscured by the growth of nitrogen-fixing Clostridia. Efforts to obtain differential inhibition of Clostridia with antibiotics failed, as did the use of several different carbon compounds in the medium instead of mannitol. (Jackson, Brown and Burlingham.)

Distribution of Azotobacter *in soil*

The numbers of *Azotobacter* varied in samples taken at the same time within a single experimental plot. On Broadbalk plot 2, which receives dressings of FYM, the numbers varied in twelve separate samples from 258 to 56,000/g. dry weight soil. In a series of twelve samples taken from the upper 5 cm. of Park Grass plot 13 (limed section receiving alternate dressings of FYM and fish guano) the numbers of *Azotobacter* ranged from fewer than 12 to 298/g. dry weight soil.

Preliminary studies on the vertical distribution of *Azotobacter* showed increasing numbers down to a depth of 10 cm. in Park Grass plot 13. In a fertile garden soil (pH 6·8), *Azotobacter* was relatively abundant to a depth of 20 cm., but numbers rapidly decreased below this depth.

The rhizospheres of uninoculated spring wheat, winter wheat and sugar beet grown in a clay loam soil (Rothamsted), or spring wheat grown in Fen soil (Waterbeach, Cambridge), did not contain significantly more *Azotobacter* than the non-rhizosphere parts of the soils.

The establishment of *Azotobacter* in the rhizosphere after inoculating the seed was studied in greatest detail with spring wheat grown in peat soil at Waterbeach. The seed was inoculated by spraying on the day of sowing; an average of 23,000 viable bacteria was recovered per seed. *Azotobacter* were counted on six occasions up to the 23rd week after sowing. The average number in the rhizosphere of inoculated plants throughout this period was 2,600/g. dry weight soil, compared with 227/g. for uninoculated plants and 171/g. for non-rhizosphere soil. Multiplication of *Azotobacter* in the rhizosphere during the growth of the wheat was indicated by the numbers in the rhizosphere being maintained throughout the sampling period, despite the fact that the root system was growing and so increasing the amount of rhizosphere soil per plant. This success in establishing *Azotobacter* is of special interest because of the negligible effect of the rhizosphere in the uninoculated plants. The *Azotobacter* on different parts of the roots of young wheat (5 weeks) were counted; roots within 2·5 cm. of the crown of the plant (the proximal fraction) had 30–100 times more *Azotobacter* than roots of uninoculated plants, the distal fraction 4–30 times more and the lateral roots 20–80 times more. Adventitious roots of plants examined when 8 weeks old had 4–9 times as many *Azotobacter* in the proximal fractions (including laterals) as in the distal fractions; *Azotobacter* on the whole root system of the inoculated plants were 70 times greater than in control soil. These results show how extensively the root system can be colonised from an original inoculum on the seed. (Jackson, Brown and Burlingham.)

BOTANY DEPARTMENT

D. J. Watson

P. J. Goodman was appointed to work on the physiology of the sugar-beet plant, with a grant provided by the Sugar Beet Research and Education Committee; he joined us in September. Mr. Jamaludin bin Lamin, of the Department of Agriculture, Malaya, came in August to spend a year here.

Joan M. Thurston and P. J. Welbank contributed to the second Symposium of the International Research Group for Weed Control, held at Oxford in April.

Physiology of Growth

Competition within a wheat crop

The results of the experiment done in 1959 (*Rep. Rothamst. exp. Sta.* for 1959, p. 80) to compare the growth of winter wheat in normally spaced rows (7 inches), widely spaced rows (21 inches) and edge rows (normal spacing on one side, and wide on the other) were analysed. In April plants in the wide and edge rows had a higher nitrogen content and began to tiller more, and during May they developed a larger leaf area and dry weight, than those in normal rows. Up to the time when ears emerged, wide rows had no more leaf area than edge rows, but they produced more dry weight. The greater dry weight per metre of edge rows than of normal rows at the time of ear emergence was attributable mainly to greater leaf area, and partly to slightly higher net assimilation rate (E), but the greater dry weight per metre of wide rows than of edge rows was caused wholly by higher E. After ear emergence, leaf area per metre of wide rows decreased less rapidly than that of edge rows. The grain yield per metre of wide rows was about twice that of normal rows, and that of edge rows was about 60% more than of normal rows, so the additional yield did not compensate for wider spacing. The differences in grain yield between wide, edge and normal rows could be accounted for wholly by the differences between them in leaf area in the period between ear emergence and harvest, and there was no evidence that at this stage variation in spacing affected the photosynthetic efficiency of leaves or ears.

Our interpretation of these results is that, during vegetative growth, competition between rows was mainly for nutrients, particularly nitrogen, but also for light, especially at the wider spacings. The relation between E and leaf area per unit area of land (leaf area index, L) for the different spacings was similar to that previously found for barley when L was varied by differential thinning (*Rep. Rothamst. exp. Sta.* for 1957, p. 90), which supports the assumption that the differences in E were caused by differences in mutual shading, i.e., competition for light. The fall of E with increase in L implies that the rate of dry matter production during the vegetative phase would be maximal with L about 6, which is probably within

the current range for wheat crops. The highest value of L in this experiment was just over 5.

After ear emergence there was apparently no competition for light, presumably because at this stage the photosynthetic tissue consists mainly of flag leaf and sheath, peduncle and ear, which are so fully exposed at the top of the plant that closer packing in narrow than in wide spacings does not much increase mutual shading. The absence of shading effects indicates that mutual shading may not limit grain yield until leaf area duration after ear emergence has much higher values than in this experiment.

Mature straws in wide and edge rows had a slightly greater mean diameter than in normal rows, and large straws from wide and edge rows required a greater force to bend and buckle them in the first or second internode than did straws of the same diameter from normal rows. These two effects may together account for the frequently observed tendency for edge rows of cereal plots to remain standing when the inner rows are lodged; in this experiment there was no lodging. (Watson and French.)

Effects of drought on plant growth

When sugar-beet crops were watered after a prolonged drought they temporarily grew faster than plants that were never subjected to water stress (*Rep. Rothamst. exp. Sta.* for 1959, p. 77). An experiment was done in 1960 to test whether barley responds like sugar beet to watering after drought, and, more generally, to study the effects of soil water deficit on the barley crop.

Proctor barley was grown in the Dutch-light glasshouse, with or without nitrogenous fertiliser applied at sowing. During the period of vegetative growth the following treatments were compared: (*a*) *minimal water stress* maintained by frequent watering, (*b*) *short drought*: no watering for 3 weeks after the three-leaf stage, (*c*) *long drought*: no watering for 5 weeks after the three-leaf stage. After the drought periods the crops were watered as for (*a*) until ear emergence. Each of these treatments was followed by a comparison of watering (*d*) with no watering (*e*) from ear emergence to maturity. On the plots that received nitrogenous fertiliser the plants tended to lodge, and the amount of water applied in treatment (*d*) had therefore to be restricted, so there was a water deficit at the end of the period and the difference between treatments (*d*) and (*e*) was smaller than was intended. Treatment (*c*) produced short, stiff, dark-green shoots that did not lodge.

During the drought periods of treatments (*b*) and (*c*), growth in dry weight and in shoot number was less than in the watered plants of treatment (*a*). The effect on dry matter accumulation was caused by decreased leaf growth; net assimilation rate was unaffected. When the drought was broken many new shoots were produced, some of which persisted to harvest. Thus, treatments (*b*) and (*c*) increased the total number of ears, although the proportion of fertile shoots was decreased; they also hastened ear emergence.

When watered after drought, plants of treatments (*b*) and (*c*) had higher relative growth rates than those of treatment (*a*), but, in contrast to the results for sugar beet, the spurt of growth was

apparently caused wholly by delayed senescence of leaves increasing leaf area, as net assimilation rate was not increased.

The decrease in total dry weight caused by drought persisted until the ears were nearly ripe, and slightly depressed ear dry weight, but there were no significant effects on final yield. Treatments (*b*) and (*c*) delayed ripening of the ears, and their longer growth period may have helped to offset the effects of drought. Treatment (*e*) hastened ripening of the ears. Drought had more severe effects on the plants that received nitrogenous fertiliser, but they recovered more rapidly when watered.

An attempt was made to induce water stress in plants growing in culture solutions, by adding an inert solute to the solutions, to produce effects of drought with better control than is possible in soil cultures. The solutes usually employed, sucrose and mannitol, are readily decomposed by bacteria and can be absorbed by the plant, so they are useless for experiments lasting more than a few hours. Polyethylene glycol (PEG) was studied as a possible alternative. It exists in a range of molecular weights, is microbiologically stable and apparently does not penetrate potato slices. The response of dwarf French bean plants to PEG added to the culture solution depended on the molecular weights of PEG, the age of the plant and the environment, as well as on the concentration of PEG. An osmotic strength of 7 atmospheres usually caused wilting, followed by recovery of turgor that was slower with the larger molecules. Leaf growth rate and relative turgor were permanently decreased, and often leaves were scorched or became chlorotic. The recovery from wilting implies either that PEG entered the plant or that the plants became adapted to the increased water stress by metabolic changes. (Orchard.)

Growth on different soils

Hitherto, our studies by growth analysis of the physiological causes of variation in crop yield have been confined to Rothamsted farm, but the appointment of P. J. Goodman provided the opportunity to investigate variation in yield between different soils. Some preliminary work was done in 1960 to gain experience of the problems involved in doing growth analysis at widely separated places. Samples were taken at intervals from June to October from sugar-beet crops grown with or without nitrogenous fertiliser at four centres, including Rothamsted. At three of the four centres the yields were similar when nitrogenous fertiliser was applied, but they were more variable without nitrogen, suggesting that the main variable factor between the soils was nitrogen supply. Presumably there was no lack of water at any centre. The fourth centre yielded less, probably because of the small and irregular plant population. Variation in yield of dry matter between soils was closely correlated with leaf-area duration. Net assimilation rate was lower on the higher-yielding soils, presumably because it decreased with increase in leaf area through increased mutual shading of leaves. Apart from this there was no evidence of variation in photosynthetic rate between soils. The partition of dry matter between leaves and roots was similar at all the centres. (Goodman, Thorne and Watson.)

Photosynthesis at different heights in crops

The net assimilation rate (E) of sugar beet decreases much less rapidly than E of kale with increase in leaf area index (L), and this has been attributed to more uniform illumination of the foliage of sugar beet than of kale, associated with a different spatial arrangement of the leaves. If this explanation is correct, the rate of photosynthesis should change less with height in a sugar-beet crop than in a kale crop. An attempt to demonstrate this by comparing short-period increases in dry weight of crops from which varying fractions of the leaf area had been removed was inconclusive, because estimates of dry-matter increments of large plants are subject to relatively high errors (*Rep. Rothamst. exp. Sta.* for 1959, p. 81). A less laborious method of estimating the rate of photosynthesis at different heights in a crop, which should be more precise and adaptable and avoids confusing height variation with variation from differences in age of leaves, has therefore been developed. It depends on estimating the net assimilation rate of small plants (phytometers) placed within the crop. Sugar-beet seedlings proved the most suitable of several species tested, because their stems do not elongate. They are grown in solution culture, and for the field measurements are transferred to glass vessels provided with a reservoir of nutrient solution to last 1 week, and designed to minimise shading. The initial and final leaf area and dry weight of each phytometer are estimated or determined directly, and from these measurements net assimilation rate and other growth parameters can be calculated. Phytometer growth was measured at various times in crops of barley, kale, potatoes and sugar beet at various heights from 20 cm. above ground level to just above the crop, with eight replicates at each height. Calculations of E on the electronic computer are not yet complete. The vertical distribution of leaf area in the crop was also measured. In the later stages of growth of barley, kale and sugar beet there was very little leaf area within 20 cm. from the ground, but the potato crop had a large fraction of its leaf area in this zone throughout the growth period. So, except in the potato crop, the growth of the phytometers at 20 cm. from the ground can be used as an estimate of the interception of light by the foliage of the crop. It was least in barley; growth of phytometers at 20 cm. in barley in June and July was three-quarters of that above the crop; for kale at the end of June it was a half and in early August a quarter; for sugar beet in August it was a half. These results show that photosynthesis was still possible at the bottom of the crop profile until late in the growing season. (Leach.)

Photosynthesis by ears of Proctor and Plumage Archer barleys

Field crops of Proctor barley consistently yield more than Plumage Archer, and the difference has been attributed to more photosynthesis by the ears of Proctor than of Plumage Archer. Previous experiments to test this by measuring the effect on yield of shading ears to prevent them photosynthesising were done on plants grown in pots, but in these conditions the two varieties gave similar yields; the experiments were therefore repeated on field crops.

Newly emerged ears of the two varieties were selected at random, covered with opaque nylon or cotton fabric shades, and their yields compared with those of unshaded shoots. Shading decreased grain yield per ear by 39% for Proctor and by only 15% for Plumage Archer. It decreased the 1,000-grain weights of both varieties by about 18%. The number of grains per ear of Proctor but not Plumage Archer was decreased by shading, although both varieties were covered when the ears were almost fully emerged; previously, shading at this stage had negligible effects on grain number. Even if there were no effect on grain number, and photosynthesis per ear were similar for the two varieties, the contribution of ear photosynthesis to grain yield per acre would still be greater for Proctor, because it had 70% more ears per acre than Plumage Archer.

Previous experiments showed that ear : shoot weight ratio was greater for Plumage Archer at ear emergence, but at maturity it was greater for Proctor, and this reversal occurred in both shaded and unshaded shoots (*Rep. Rothamst. exp. Sta.* for 1959, p. 79). In a pot experiment in 1960 the reversal of the varietal difference in ear : shoot dry-weight ratio between ear emergence and maturity depended mainly on the greater relative growth rate of Proctor ears, especially when shaded, but also the decrease in dry weight of shoot was slightly greater for Proctor than for Plumage Archer. As in 1959, leaves of Proctor survived longer than those of Plumage Archer and, when the ears were shaded, appeared to be more efficient in producing dry matter. Shading ears had similar effects in both varieties: it decreased ear weight by 33%, and stem weight by 8%, and increased leaf-area duration between emergence and maturity by 8%.

The CO_2 uptake by photosynthesis and loss by respiration of shoots similar to those of the ear-shading experiment were measured directly with an infra-red gas analyser. The rates per ear of apparent photosynthesis during the day and of respiration at night never differed significantly between Proctor and Plumage Archer. They changed little between 10 and 24 days after ear emergence, but fell considerably after 35 days, when some green colour still remained in the awns. The rate of apparent photosynthesis per shoot of the flag leaf and sheath and peduncle, the parts of the shoot that supply assimilate to the ear, was similar to that of the ear 10 days after emergence, 60% of the ear rate at 24 days and negligible at 35 days. It was similar for the two varieties at 10 days, but later was slightly greater for Proctor, probably because the leaves yellowed more slowly than those of Plumage Archer. The respiration rates of the flag leaf and peduncle did not differ between varieties, and fell with age. Calculations from hourly rates of photosynthesis and respiration showed that photosynthesis by the ear contributed 30% of its final dry weight, made up of an increase of 45% from photosynthesis and a loss of 15% from respiration. Of the final ear weight 15% was present at emergence and 55% came from the shoot. Shoot photosynthesis provided more material for the grain than ear photosynthesis until 10 days after ear emergence, but by 24 days the relative importance of shoot and ear was reversed.

The rate of photosynthesis of the ear remained constant for most of the period between ear emergence and maturity, but that of the flag leaf and peduncle decreased, both per shoot and per unit

area. Independent evidence that the rate of apparent photosynthesis of leaves falls with age was obtained from measurements on the seventh and eighth leaves of Proctor and Plumage Archer shoots made in artificial light during 40 days between full expansion and the start of senescence. The rate fell by 0·36 mg./dm.^{2}/day, 5% of the mean value. The photosynthesis rates of the two varieties were similar but the respiration rate per g. or per dm.^{2} was slightly greater for Proctor than for Plumage Archer. (Thorne.)

Interpretation of ear-shading experiments

Shading ears prevents photosynthesis, but presumably does not decrease respiration. Therefore, according to the direct measurements of photosynthesis, shading ears should decrease ear weight of barley by about 45%, but in numerous experiments the decrease was only 15–30%. Possible causes of this discrepancy are: (1) increased translocation from the shoot into shaded ears—shoots and roots of shaded plants sometimes lost more weight after ear emergence than those of unshaded plants; (2) increased photosynthesis by the leaves when ears are shaded—leaves often stay green longer on shaded than on unshaded shoots; (3) decreased ear respiration—shaded ears may lose less weight by respiration than unshaded ones because they are smaller, but this is unlikely, because respiration rates of unshaded ears at 10 and 24 days after emergence were similar although their weight increased from 0·4 to 0·9 g. Experimental estimates of (1) and (2) rarely accounted for all the differences between observed and expected effects of shading. Estimates of the relative importance of ear photosynthesis in different varieties made by shading ears are valid only if the causes of underestimation of photosynthesis do not vary with variety. There is no evidence that they do between Plumage Archer and Proctor. (Thorne.)

Effect of gibberellic acid on the growth of potato

Experiments in 1958 and 1959 showed that potato plants sprayed with gibberellic acid (GA) solution had larger leaves, and though at first this increased the rate of dry-matter production, the net assimilation rate eventually fell below that of unsprayed plants, and their final yield was not increased (*Rep. Rothamst. exp. Sta.* for 1958, p. 75, and 1959, p. 72). The deterioration in photosynthetic efficiency of sprayed leaves, accompanied by yellowing and earlier senescence and by a decrease in nitrogen content % of dry weight or per unit area, occurred sooner when the initial nitrogen supply was low than when it was high, but addition of ammonium nitrate to the soil or repeated spraying of the leaves with urea solution after treatment with GA did not prevent or delay the onset of chlorosis. Further analysis of the results of the 1959 experiment showed that late N application increased the rate of leaf production on lateral branches and the leaf area per plant but not leaf size. These effects were independent of the spraying with GA. In contrast with nitrogen, GA increased leaf area per plant solely by increasing leaf size. Additional N did not arrest the decrease in N content of the leaves of plants sprayed with GA. The absence of interactions between GA and N treatments does not support the hypothesis that the

chlorosis, impaired photosynthesis, and more rapid senescence of leaves caused by GA are the result of acute nitrogen deficiency.

In a similar experiment done in 1960, in larger pots holding 16 kg. of soil instead of 10 kg., the increase in dry-matter production by GA was more persistent and the final yield was increased. Also, the effect of GA increased with increase in N supply. In the previous experiments the effect of GA may have been restricted in some way by the amount of soil per pot, but the cause is not yet known. (Humphries and French.)

Leaf-growth substance from dwarf French bean leaves

A leaf-growth substance similar to gibberellic acid (GA) was found in extracts of leaves of dwarf French bean seedlings (5.9). Zones from chromatograms of leaf extracts with R_f similar to GA increased the growth of disks cut from dwarf French bean leaves, when tested either in light or in darkness with disks from plants grown either in light or in darkness, but the assay was more sensitive with disks cut from etiolated plants. An inhibitory zone close to the starting-line appeared on chromatograms assayed in light.

An attempt was made to characterise the substance more precisely by biological tests that are more specific for gibberellins. The substance promoted extension of internodes of Meteor dwarf pea seedlings; this confirms that it is a gibberellin. Extension of the hypocotyls of two-day-old lettuce seedlings was stimulated by as little as 0·01 GA in light, but no activity in this test was found on chromatograms of leaf extracts in zones corresponding to the GA marker spot. This shows that the substance is not GA. Phinney * showed that some dwarf mutants of maize can be made to grow to normal height by supplying gibberellins. Leaf-sheath growth of dwarf mutants d-1, d-3 and d-5 is promoted by GA, but the leaf-growth substance had no effect on d-1, some effect on d-3 and most effect on d-5. Similar activity on d-5 but not on d-1 has been attributed by Phinney to Bean Factor II. Thus, the gibberellin extracted from dwarf French bean primary leaves that promotes leaf expansion is not GA, but has properties similar to Bean Factor II, now known as GA_5.

When apical growing points of dwarf French bean plants were excised the primary leaves grew larger and contained more GA-like growth-substance than leaves of intact plants. The epicotyls were also longer. Removing the cotyledons before the primary leaves unfolded prevented the leaves expanding and GA-like growth-substance accumulating in them. Later removal of cotyledons had less effect. Soaking seed in water for 24 hours caused no detectable loss of seed dry weight but decreased the area of the primary leaves and their content of GA-like growth-substance. This suggests that growth-substance was leached from the cotyledons. However, previous work showed that the sensitivity of etiolated bean leaf disks to GA was not increased by prolonged soaking of the seed or removal of cotyledons. (Wheeler.)

* Phinney, B. O. (1956). *Proc. nat. Acad. Sci., Wash.* **42**, 185–189.

Gibberellins in potato leaves

A growth-substance active in the etiolated-bean-leaf disk test, with R_f similar to GA and to the leaf-growth substance present in leaves of dwarf French bean, was found on chromatograms of extracts of potato leaves. Spraying potato plants with aqueous GA (50 mg./l.) soon after the 15th leaf began to expand increased the content of gibberellin-like growth-substance of that leaf by five times and increased its growth rate. The gibberellin content of sprayed and unsprayed leaves changed little during 23 days after spraying, but had decreased by the 37th day, when leaf expansion had nearly ceased. These results show that an endogenous gibberellin-like leaf-growth substance is present in potato leaves, and affects their growth rate similarly to externally applied GA. (Humphries and Wheeler.)

Effect of light quality on growth and growth-substance content of plants

The increased growth of dwarf French bean plants in artificial light when fluorescent tubes were supplemented by tungsten-filament lamps (*Rep. Rothamst. exp. Sta.* for 1959, p. 74) was further studied, and stems and leaves were analysed to see whether the effects of additional incandescent light were related to the content of growth substances. The main effect of incandescent light, increased length of internodes, occurred consistently in seven varieties of dwarf French bean. Incandescent light made stems elongate more in 16-hour than in 8-hour photoperiods. Plants were exchanged between treatments consisting of fluorescent light with or without incandescent light, when 12 days old, leaving control plants to continue with their previous treatment. When they were harvested after 25 days, stem height was increased only by incandescent light in the later period, and there was no interaction between early and late incandescent light treatments. Dry weight was usually increased by additional incandescent light, perhaps because stem elongation brought the leaves nearer the lamps, and hence into a higher light intensity.

The increased growth of internodes of Canadian Wonder dwarf French bean plants grown with additional incandescent light was associated with more of both gibberellic acid-like and indolylacetic acid-like growth substances. The content of IAA-like growth-substance increased as the plants aged, but that of GA-like growth-substance did not. (Wheeler.)

Boron and adventitious root formation

A remarkable interaction of boron and light on adventitious root formation reported last year (*Rep. Rothamst. exp. Sta.* for 1959, p. 77) was confirmed in 1960. Dwarf French bean plants were grown at 20° in soil in cabinets lit by fluorescent tubes with a 16-hour photoperiod. When the first pair of leaves was fully expanded the hypocotyls were cut and placed in nutrient solution with or without boric acid. In addition to light from fluorescent tubes, some plants received light from incandescent lamps either before or after the hypocotyls were cut, or throughout both periods or during neither period. After 14 days the numbers of roots and root initials on the hypocotyls were counted, and the roots cut off and

weighed. Incandescent light given before or after the hypocotyls were excised decreased the number and weight of adventitious roots on plants without boron, but had no effect on root formation of plants given boron. Or, in terms of boron action, boron had little effect on plants illuminated with fluorescent light only, but lack of boron decreased root formation by plants that received supplementary incandescent light. The growth in dry weight of the hypocotyls without boron was decreased by incandescent light given before but not after the hypocotyls were cut. (Humphries.)

Growth of rooted detached leaves

The changes that lead to rapid senescence and death of a detached leaf are arrested when roots are formed on the petiole, and the system may then begin to accumulate dry matter. After rooting, a detached leaf increases little in area, but its life may be prolonged far beyond what it would have been had it remained attached to the plant. The behaviour of rooted-leaf cultures is therefore being examined, to find whether they can be used to study the factors that control leaf expansion and longevity, and the dependence of photosynthesis on growth.

When primary leaves of dwarf French bean were cut from the plant and kept in light with their petioles dipping in nutrient solution roots began to appear in 7 days. During this time growth in dry weight was small, but after roots appeared the rate of growth increased. When petioles were treated with indolylacetic acid before they were placed in nutrient solution more roots were formed, and leaves so treated had a higher growth rate and net assimilation rate than leaves rooted in nutrient solution alone. However, the net assimilation rate of rooted leaves, even after treatment with IAA, was much below that of intact seedlings grown in the same conditions. These results indicate that the rate of photosynthesis depends on the rate at which photosynthetic products are used in growth. Adding kinetin to the nutrient solution suppressed root formation but induced a large growth of callus (5.3) and decreased net assimilation rate only slightly below that of rooted leaves, showing that callus affects the rate of photosynthesis in the same way as roots. (Humphries.)

Weed Studies

Wild oats

Survival of seeds under temporary ley. In the fifth and last year of the experiment at Rothamsted (*Rep. Rothamst. exp. Sta.* for 1959, p. 81) on plots ploughed in autumn 1959 after 5 years under ley, the number of seedlings of *Avena fatua* per 10 sq. yd. was 7, compared with 6 in 1959, and 90 before the ley was sown. The residual population of viable dormant seeds is evidently still far from being exhausted.

The experiment on a field in Northamptonshire with a mixed infestation of *A. fatua* and *A. ludoviciana* also ended, because the ley was ploughed in spring 1960. The number of seeds in 14 lb. of dry soil had fallen from 41 ± 7 in 1959 to 23 ± 3 in 1960.* Soil samples taken from the field in 1959 and kept watered in the glass-

house have already produced seedlings from 50% of the estimated number of seeds present, proving that the seeds are viable. After 6½ years under ley, this field still had over 2 million wild-oat seeds per acre. (Thurston.)

Wild oats from other countries. Plants of 84 European and 10 Australian selections of wild oats were grown in pots to compare with 8 British sorts. European *A. fatua* and *A. ludoviciana* behaved like their British counterparts, except that their panicles emerged a few days earlier. Australian selections of these species differed greatly from both European and British, their panicles emerged about 3 weeks earlier and were shorter, with fewer seeds in each, and they had nearly twice as many panicles per plant. *Avena barbata* from France and Australia had the same prostrate habit as *A. barbata* from Malta (*Rep. Rothamst. exp. Sta.* for 1958, p. 85). Those from Australia reached 50% panicle emergence about 4 days before the French, showing a tendency to earliness similar to, but smaller than, that found for the other species. Over 90% of the seeds of most of the selections from the plants grown in the glasshouse were dormant when sown in October 1960, except that seeds of British and two European selections of type fM of *A. fatua*, the first seeds of spikelets of *A. ludoviciana*, and seeds of *A. barbata* from France and Australia (unlike those from Malta) were all non-dormant. (Thurston.)

International experiments on A. fatua. We collaborated in two experiments arranged by the International Research Group for Weed Control. Seeds of *A. fatua* were collected in nine countries, and samples of each collection were sent to three laboratories where their susceptibility to new herbicides intended for wild oat control will be tested, and to Rothamsted for botanical analysis and identification.

For the second experiment on the effect of storage conditions on dormancy and viability, ripe seeds were collected when ready to shed, exposed outdoors on the surface of the soil for 1, 2 or 3 months, and then stored for 0–6 months at 10° or 20° in the laboratory. Immediately after collection, and after each period of outdoor exposure and laboratory storage, seeds were set to germinate at 10° or 20° for 3 weeks, to determine how many were non-dormant. The viability of the residue was tested by germination after cutting off the distal ends. At Rothamsted none of the treatments decreased viability or dormancy below 95% during the first 4 months, although in a similar experiment in Sweden in 1960 2 months' dry storage decreased dormancy from 100 to 50%. Results have not yet been obtained from other centres. (Thurston.)

Broadbalk weeds

Alopecurus myosuroides (black grass) and *Avena ludoviciana* (winter wild oat) were much more abundant in 1960 than in recent years because of the early sowing date (19 October 1959), which allowed all the seedlings to survive undisturbed by seedbed cultivations.

The series of soil samples taken from 1955 to 1960 from Section 1a, which has returned to continuous wheat, and Section 1b, which remains in the fallow cycle, show that the use of herbicides on

Section 1b has decreased the numbers of seeds of *Ranunculus arvensis* (corn buttercup) and *Vicia sativa* (common vetch) in the soil. The numbers of *Medicago lupulina* (black medic) and *Alchemilla arvensis* (parsley piert) seeds were also decreased, but they had increased so much in 1956, when no herbicide was used, that they are still above the numbers on Section 1b, which was fallowed in 1956. Seeds of *Papaver* spp. (poppies) were also much decreased by the 1956 fallow on 1b, but by 1959 they were again more numerous than on 1a. *Alopecurus myosuroides*, unaffected by herbicides, increased in the continuous wheat, although late sowing has helped to control it all over Broadbalk. (Thurston.)

Survival of arable weed seeds in Geescroft wilderness

Natural woodland has grown undisturbed on this area since arable cultivation ceased in 1867. Samples were taken from the leaf-litter, surface humus, the formerly ploughed layer of the soil and the subsoil in February 1960, and kept watered in pans in the glasshouse. Seedlings of *Rumex obtusifolius* (broad-leaved dock), *Anagallis arvensis* (scarlet pimpernel) *and Vicia hirsuta* (hairy vetch) have appeared from the ploughed layer, but not from the litter or humus above it, suggesting that these species have survived as dormant seeds for many years. Plants of *R. obtusifolius* were found in 1903, and of the other two species in 1913, but records were infrequent, and how long these species continued to fruit is not known. *A. arvensis* and *V. hirsuta* are not now found growing in the Wilderness, and *R. obtusifolius* grows only at the edges, not near where the samples were taken. Viable seeds of *Urtica dioica* (stinging nettle) and grasses were also found in the ploughed layer, but as they were also present in the layers above, and the species still grow in the wood, long survival of these seeds cannot be assumed. (Thurston.)

Competition between crop and weeds

Weed density and crop yield. The results of the experiment in 1959 to measure effects of varying densities of different weeds on yield of spring wheat (*Rep. Rothamst. exp. Sta.* for 1959, p. 83) have been statistically analysed, but their interpretation still presents difficulties. In two wheat fields, 90 small plots were protected with polythene sheet when the field was sprayed with hormone weedkiller, and the weeds of each species were counted or estimated. The yields of wheat on the unsprayed areas and on contiguous sprayed areas were determined. Partial regression coefficients of the yield of the unsprayed plots on log weed density were calculated. When the yield of sprayed plots was included as an additional independent variate in the regression, to correct for variation in fertility between the unsprayed plots, the accuracy of the regressions on weed density was not improved. The explanation may be that the yield on the sprayed plots was already affected by the weeds present before spraying, or that the spraying was only partially effective in eliminating weed competition.

The only weed species that affected the wheat yield in both fields significantly were *Atriplex patula* (orache) and *Polygonum aviculare* (knot grass). Within the range between 10 and 3,000 seedlings/sq. yd., a ten-fold increase in density decreased wheat yield by 10% for

A. patula and 6% for *P. aviculare*; 100 plants/sq. yd. decreased wheat yield by 20% for *A. patula* and by 12% for *P. aviculare*. *Chenopodium album* (fat hen) had no significant effects on yield, although there were up to 3,000 seedlings/sq. yd., but few of these survived to become mature plants.

In 1960 the experiment was repeated on two fields of winter wheat, where the principal weed species at the time of spraying in spring were *Polygonum aviculare*, *P. convolvulus* (black bindweed), *P. persicaria* (red shank), *Poa* spp. (meadow grass), and autumn-germinated *Galium aparine* (cleavers) and *Stellaria media* (chickweed). Inspection of the data, now being analysed on the electronic computer, suggests that only weeds that germinated in the previous autumn (particularly *Galium*) had much effect on yield. Similar observations were also made on a barley experiment on weed control by a triazine herbicide. (Welbank and Witts.)

Survey of competitive effects of common weed species

Two more experiments of the type already described (*Rep. Rothamst. exp. Sta.* for 1958, p. 86, and for 1959, p. 84) were done to measure the effects on the growth of single plants of wheat or kale of growing 16 weed plants with them in the same pot. *Chenopodium album* as a standard was compared with *Matricaria maritima* ssp. *inodora* (scentless mayweed), *Polygonum convolvulus* and *Veronica persica* (Buxbaum's speedwell) in the first experiment, and with *Alopecurus myosuroides*, *Anagallis arvensis* and *Sinapis arvensis* (charlock) in the second. *Atriplex patula* was also included in both experiments, but again it did not germinate satisfactorily. Pre-treatment of the seeds of some species, e.g., by chilling or treatment with sulphuric acid, was necessary to make them germinate, and it was difficult to time the treatments to obtain simultaneous germination of all species and crops. This may account in part for some of the differences between species.

In the first experiment *Polygonum* had a greater competitive effect than the other weeds; *Matricaria* and *Veronica* had similar effects, less than that of *Chenopodium*. The percentage reduction of crop yield by *Chenopodium* decreased with increase in nitrogen supply, but with the other species there was no evidence that competition was for nitrogen.

The test of *Chenopodium* in the second experiment was invalidated by delayed germination. *Anagallis* had a negligible effect on the crop. *Alopecurus* had slightly less effect than *Polygonum* in the first experiment. *Sinapis* was the most aggressive of the weeds tested. It decreased the dry weight of kale by 95%, and of wheat by 80%, and although this large effect may have been partly caused by earlier germination of the pre-chilled weed than the crop, *Sinapis* is evidently a very powerful competitor. (Welbank.)

Competitive effects of Agropyron repens (*couch grass*)

The work in 1958 and 1959 to find whether the harmful effect of *Agropyron repens* on crops can be attributed to competition for nutrients in the soil (*Rep. Rothamst. exp. Sta.* for 1959, p. 84) was continued with a test of the effect of phosphorus supply on competition with radish, and its interaction with nitrogen supply.

Although increase in P supply increased the dry weight of radishes grown alone, the competitive effect of *Agropyron* could be explained by its effect on N uptake.

When rhizomes and roots of *Agropyron* decay in poorly aerated soil, substances toxic to seedlings are formed (*Rep. Rothamst. exp. Sta.* for 1959, p. 85). The rate at which these substances are produced was studied by adding pieces of rhizome to moist Woburn soil in glass jars, which was incubated at 20°. In some jars aeration was impeded by adding water and closing the mouth of the jar with a bung. Extracts of the soil were filtered and assayed by measuring their effects on radicle and hypocotyl elongation of rape seedlings. The first measurements were made after 12 days, and there was little increase in toxicity at later times. Evidently toxicity developed rapidly in the early stages of decay, and changed only slowly thereafter. Anaerobic preparations decreased radicle growth by 55% and aerobic preparations by only 5–10%. Toxicity was the same whether fresh rhizomes or rhizomes killed by drying or freezing were used. The harmful effects of anaerobic preparations on hypocotyl growth were much less than on radicle growth, and aerobic preparations tended to increase hypocotyl length. The toxicity of the extracts was unaffected by autoclaving for 25 minutes at a pressure of 15 lb./sq. in. (Welbank.)

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

G. Jenkins resigned and the vacancy was filled by J. W. Sturrock. During the summer Mrs. N. Ayles and Miss S. Herklots joined the staff temporarily to help in cooking leaf protein.

At the invitation of the Jamaican Government, N. W. Pirie visited Jamaica to study the possibilities of making leaf protein there on a large scale; as a result, a local committee was set up and one of our pulpers was sent to Jamaica in October. We hope to send a press soon. N. W. Pirie attended a "Conference on Protein Needs" and the Vth International Congress on Nutrition in Washington.

The Extraction of Protein from Leaves

Laboratory scale investigations

As experience increases, our confidence in judging, from the appearance and feel of a leaf, whether protein will be readily extracted from it, also increases. But some batches extract unexpectedly badly, and this cannot always be explained by the usual inhibitory factors, such as acidity or the presence of tannins. Work on the reasons for poor extraction can proceed in two ways: by studying the same species in different physiological states and by comparing species.

Winter wheat was sampled and minced at intervals; the sap was fractionated centrifugally and the ratio of chlorophyll to nitrogen determined on the fibre and sap fractions. In young leaves (less than 170 days from sowing), the ratio was about the same in sap and fibre, which suggests, as did earlier work, that the protein remaining in the fibre is not a special form but remains there for mechanical reasons. Older leaves have relatively more chlorophyll in the fibre, and the chloroplast fraction in the sap is a smaller proportion of the total extracted protein than in young leaves; this suggests that mechanical entrainment of chloroplasts increases as leaves age and that the increased entrainment is associated with diminished extractability of protein. The technique used in the experiment was not adapted to determine which of the changes accompanying maturity was responsible for this extra entrainment. The experiment is being repeated in a more refined manner. No clear pattern emerges from one similar comparison between 10 plant species taken at arbitrary ages. The ratio of chlorophyll in the fibre to chlorophyll in the extract was not correlated with total protein extraction. (Singh.)

Detergents will extract protein that remains associated with the fibre after leaves are minced or extruded through a fine slot. Their action is most apparent on fibre that has already been extracted with alkali because the optimum conditions for extraction can then be arranged without having salts present in high concentration. In

this way 90–95% of the protein can be extracted even from tobacco leaves up to 15 cm. in width, provided they are still in good condition. (Festenstein.)

Several components of leaves and other tissues are damaged by exposure to air during the first stages of extraction, and several workers have described glove boxes and similar pieces of equipment in which extracts can be made anaerobically. But their use requires very large volumes of inert gas. With slight modification, the arrangement that we use for grinding leaves by forcing them through a narrow slot can be used anaerobically. It gives reproducible results, is quick in action and, because of its small volume, economical with inert gas. (Pirie.)

Gibberellic acid has been used extensively in the treatment of crops, but the reported effects on the dry matter and crude protein yields vary widely. An experiment, using spring vetches (*Vicia sativa* L.), was designed to measure the effect of gibberellic acid on both the dry matter and crude protein yields, and on the extraction of protein from the leaf. A single application (0·08 g. gibberellic acid in 1·0 l. water per 10-foot × 6-foot plot) did not significantly affect yields of dry matter or crude protein from the foliage taken at the first cut, 10 weeks after sowing; there was also no significant difference in the yields of extracted protein at this stage. However, the yields of dry matter and crude protein were both significantly decreased at the second cut, 4 weeks later. Two additional applications of the same amount of gibberellic acid, after the first cut, further decreased these yields at the second cut. The single and triple applications lowered the yields of extracted protein at the second cut enough for the difference in total extracted protein to be significant. Spraying with gibberellic acid before the second cut only, did not affect the dry matter but lowered the yields of both crude protein and extracted protein, though the totalled yields from two cuts were not significantly lowered. It is clear that, with this crop, the yield of protein is not increased by treatment with gibberellic acid. (Byers and Jenkins.)

Large-scale preparations

As in past years, the main work in spring was to produce enough protein for feeding trials. Pig-feeding experiments at the Rowett Research Institute were so successful that comparisons between different leaf species are being undertaken. These results have also interested various laboratories concerned with human nutrition, and 10–20-lb. lots of dry protein have been sent to the Tropical Metabolism Research Unit (Jamaica), Department of Pediatrics (Kampala), Department of Pediatrics of New York University School of Medicine and the Instituto du Nutrición de Centro America y Panama (Guatemala). Preliminary results at the first of these are encouraging.

A new pulper is now in use that is, in principle, the same as the one we have been using for several years, but with various dimensions and details altered to facilitate cleaning and give more economical running. It is satisfactory, and another is being made incorporating still more improvements. (Davys and Pirie.)

The equipment used for large-scale freeze-drying has been radically improved so that we can now freeze 5–8-lb. lots of moist

protein within a few seconds and get satisfactory drying in 2 days to a soft attractive product. This equipment is being still further improved to meet the increasing demand for protein. The very large surface exposed by this dry material raises oxidation problems, because the leaf lipids are highly unsaturated and give leaf protein a characteristic flavour as they oxidise. Many of the flavours that, by convention, we relish, are also the consequence of oxidation of fats; nevertheless, with a novelty like leaf protein, it seems wise to aim at having as little flavour as possible. Considerable effort has therefore been put into a study of vacuum packing, nitrogen packing, the use of antoxidants and the selection of the best type of container for year-long storage of dry protein. (Morrison and Pirie.)

Lipid content of leaf proteins

A systematic study of the lipid content of bulk preparations has been started. All figures quoted relate to the lipid fraction initially extracted with acid alcohol–ether, and re-extractable in alcohol–ether from the dry state. The figures are much higher than those got by simpler extraction procedures here and elsewhere. The maximum figures for a selection of crops are given in Table 1. The lipid content seemed independent of the age of the crop from which the preparation was made and of the number of times the crop had been cut. From analyses yet made <1% of the total N appears in the lipid fraction.

TABLE 1

Lipid content of leaf protein (% *of D.M.*)

Crop	Min.	Max.
Maize	25·3	26·8
Mustard	21·9	23·4
Pea vines	26·8	28·3
Red clover	24·2	30·5
Rye	31·9	33·5
Tares	24·0	25·3
Wheat	29·4	31·3

(Byers.)

PLANT ENZYME SYSTEMS

Amines and minor elements in plant metabolism

The inhibition of plant amine oxidase by reagents that react with heavy metals suggests that the enzyme is a metalloprotein. Copper and manganese are present in higher concentration than other metals in preparations purified by the method described last year, which suggests that the enzyme contains one or both of these metals. The copper and manganese compounds in these preparations have now been partially separated by chromatography on diethylaminoethyl-cellulose columns to give a copper fraction (containing 0·08–0·09% Cu and <0·01% Mn) and a manganese fraction (containing 0·10–0·15% Mn and 0·01–0·2% Cu). Most of the amine oxidase activity is in the copper fraction, which also retains the pink colour that we have suggested is a property of the amine oxidase.

Spectrographic analysis of this fraction (by H. H. Le Riche) showed that, except for zinc, the concentration of which was $<0{\cdot}06\%$, other trace elements were present at concentrations $<0{\cdot}004\%$. The results suggest that the enzyme may contain copper but not manganese, and exclude the possibility, suggested last year, that the pink colour comes from a complex of manganic manganese. With hydrazine, the primary reaction product of the pink compound is yellow and absorbs maximally at 420 mμ, which suggests an aromatic carbonyl compound. No evidence was obtained to support the suggestion of other workers that this carbonyl compound is pyridoxal phosphate. Attempts to demonstrate the liberation of pyridoxal phosphate by acid or alkaline treatment of the enzyme preparations failed.

Most of the copper can be removed from the preparations by precipitation with sodium diethyldithiocarbamate. The supernatant solution, from which the excess diethyldithiocarbamate is removed by dialysis, remains pink, but generally shows little amine oxidase activity. Most of the lost activity can be restored by adding Cu^{2+} ions. Conditions have not yet been established under which the enzyme inactivates completely in these experiments. Maximum reactivation is given with concentrations of Cu^{2+} of the order of $10^{-6}M$, though partial reactivation occurs with concentrations $<10^{-7}M$ (0·006 μg Cu^{2+}/ml.). The failure to obtain complete inactivation, therefore, may happen because the reagents used are contaminated with traces of copper.

Preliminary results suggest that the copper-free enzyme is reactivated specifically by Cu^{2+} ions. There is no reactivation with Mn^{2+}, Ni^{2+}, Co^{2+}, Zn^{2+} and Fe^{3+} ions. Copper is apparently present in the preparations in the cupric form; it reacts with 2 : 2′-diquinolyl to form the characteristic lilac cuprous complex only in presence of reducing reagents. Most complexes of cupric copper are blue or green, but the only absorption band shown by the enzyme preparation in the visible part of the spectrum is that from the pink compound. It is therefore suggested that the copper occurs as a complex with the carbonyl compound and that this complex forms the prosthetic group of the enzyme. (Mann.)

The enzymic breakdown of chlorophyll

Considerable progress has been made in the purification of chlorophyllase from sugar-beet leaves. Fractional precipitation of the protein, with acetone, from enzyme-containing extracts gives an active preparation with 50–60% of the original activity. This preparation can be dialysed against dilute neutralised cysteine solution without further loss of activity. Treating the dialysed solution with diethylaminoethyl cellulose removes all colour and some inert protein, with little loss of enzyme activity. The next step is the adsorption of the enzyme on carboxymethyl cellulose and elution with neutral phosphate buffer, which greatly increases the specific activity, but the adsorption is inconsistent and loses much activity. The best preparations have been purified 500-fold, measured on the basis of nitrogen content.

In collaboration with the Botany Department several chemicals, most of which are " growth substances " reported to increase or

decrease the chlorophyll content of plants, were studied. One of the most interesting is 3-amino-1 : 2 : 4-triazole, which prevents chlorophyll formation in wheat seedlings because chloroplasts do not develop. Chlorophyllase activity, which in normal plants is associated with the chloroplasts, however, is similar in treated and untreated seedlings. The location of the enzyme is being investigated. (Holden.)

Leaf protease

The rapid autolysis of protein in wheat sap, commented on last year, stimulated a more detailed study of the variations in enzyme level with maturity, and a comparison of wheat with other plants. Casein was used as a substrate so as to avoid uncertainties caused by variations in the nature and amount of leaf protein present, and hydrolysis was measured both by increase in non-protein-nitrogen and in free tyrosine. The former was more trustworthy because of the presence of varying amounts of tyrosinase in the extracts. Two experiments, on winter wheat sown in early August and late November, gave similar W-shaped curves when protease activity per mg. of protein N in the sap was plotted as ordinate and age as abscissa; the maximum values were four times the minimum. Of nine species, wheat had the most and maize the least activity. (Singh.)

Leaf mitochondria

Mitochondrial preparations from tobacco leaves retain much of the organisation that they have in the leaf, but they are heavily contaminated with fragments of chloroplasts disrupted during the preparation. Partial separation of chloroplast fragments from mitochondria is achieved by centrifuging the preparations in a " sucrose gradient " made by layering sucrose solutions of decreasing strengths (2–0·3*M*) in the centrifuge tube. Any starch grains and bits of cell wall present quickly sediment to the bottom of the tube, while intact chloroplasts, being less dense, form a compact layer above the most concentrated sucrose solution. Chloroplast fragments and mitochondria occupy two distinct but overlapping zones near the top of the tube.

The centrifugal conditions so far used do not separate the mitochondria and chloroplast fragments completely enough to encourage attempts to prepare chlorophyll-free mitochondria, but the separation is adequate for enzymic activities to be attributed to one type of particle or the other. Thus the distribution of fumarase and cytochrome c oxidase in the centrifuge tubes parallels that of succinic oxidase closely enough to suggest that these activities are associated only with the mitochondria. The glycollic oxidase of the preparations does not sediment at all, and seems, in agreement with last year's results, not to be attached to either of these two types of particle. (Pierpoint.)

Studies on Virus-Infected Leaves

It is often asserted that the first step in a virus infection is the separation of the protein and nucleic acid moieties of the inoculum and that the first step in virus multiplication is the formation of

nucleic acid which secondarily associates with protein. This is plausible but the evidence is unconvincing.

To study the process of multiplication, leaves infected with tobacco mosaic virus were pulped in the presence of phenol, and phenol was added to pulped leaves at different intervals after pulping. The infectivities of the aqueous part of these extracts, which contains no intact virus particles, were compared; the comparisons were made with leaves pulped at different intervals after inoculation and with systemically infected leaves. Insofar as there were consistent differences, it appeared that extracts from pulp that had lain at room temperature for 10–20 minutes (i.e., conditions in which, according to our earlier work, free virus nucleic acid would be destroyed by leaf ribonuclease) were the more infective. This result conflicts with the idea that any significant amount of the infectivity of an extract is conferred by nucleic acid that was free before the phenol was added.

The infectivity of all these extracts can be increased as much as tenfold by dialysis and, after dialysis, it can be diminished by a dialysate from either infected or uninfected leaves. The nature of this inhibition is still obscure, but it may explain differences between our results and those reported from other laboratories. (Pirie in collaboration with Bawden.)

A possible reason for the difficulties in getting purified infective preparations of some viruses is that the viruses are inactivated by the oxidizing enzymes liberated during the disruption of the leaves. Methods of disrupting the leaves, that preserve many of the intracellular components, prevent some of these reactions, and therefore might stabilise the easily damaged viruses. However, attempts to extract the unstable cucumber mosaic virus from infected tobacco leaves using the sucrose-citrate medium designed to preserve mitochondria and chloroplasts have not given encouraging results. Infective particles of the virus are extracted with it, but much better results are obtained when diethyldithiocarbamate, an inhibitor of some copper containing oxidases, is present. Indeed, in the presence of this substance, edta and citrate, which are essential components of the normal medium, hinder the extraction. The phenomenon is being further studied. (Pierpoint, in collaboration with Harrison.)

Eelworm Hatching Factors

The potato-root eelworm hatching factor

In the 1960 season, 1·34 tons of potato-root diffusate were processed, mostly by the charcoal adsorption method. Attempts to improve the yield at this stage by using ion-exchange resins failed. An average yield of 23% (10 experiments) was obtained, whereas charcoal adsorption gives an average yield of 32%. Improvements in the further purification simplified the process and increased yield by 5–10%.

The hatching factor seems to be a monobasic acid with an equivalent weight of approximately 220. Analytical results are not yet consistent, but they suggest the formula $C_{11}H_{16}O_4$. Solutions of the hatching factor have no optical rotation. Previous workers suggested that a lactone ring is part of the structure of the

hatching factor, but colour tests diagnostic of αβ- and βγ-unsaturated γ-lactones were negative. Also, the infra-red spectrum (chloroform solution) shows a strong carbonyl absorption band at 1712 $cm.^{-1}$, in keeping with the absorption of a carboxylic acid, but without a maximum corresponding to the carbonyl absorption of an αβ- or βγ-unsaturated lactone.

Beet-root eelworm hatching factors

0·89 tons of root diffusate from rape seedlings grown in soil were processed by the charcoal adsorption procedure. A further 15 gallons of root diffusate from rape seedlings grown without soil was concentrated by evaporation *in vacuo*, or by adsorption on anion-exchange material; this diffusate had about ten times the hatching activity of diffusate from seedlings grown in soil. Attention has been directed solely to the factors present in these root diffusates, which stimulate the hatching of the beet-root eelworm (*Heterodera schachtii*).

Paper chromatograms of partially purified concentrates of rape root diffusates show four to nine regions with hatching activity. The number varies with the solvent system, the concentration at which assayed and the previous treatment of the sample. The results suggest that there are one, or possibly two, substances with high R_F values (0·70–0·90) with strong beet-eelworm hatching activity, which have some similar properties to the potato-root eelworm hatching factor. These compounds are responsible for a greater proportion of the hatching effect with concentrates obtained by direct evaporation, and a lesser proportion with concentrates obtained by adsorption on charcoal. Work has continued on methods of isolation and purification of the more active hatching agents.

Urea, some amino-acids, and sugars stimulate the hatching of the beet eelworm (Wallace, *Rep. Rothamst. exp. Sta.* for 1956, p. 262), but none of these approach the efficacy of the root diffusate at the optimum concentration. Compounds of this type have been reported in root exudates, and the agents with slight hatching activity detected on paper chromatograms may be such compounds. (Clarke.)

Chemical Changes in Self-heated Hay

Samples of good hay (baled at 22% moisture, maximum temperature 40°) and mouldy hay (baled at 46% moisture, maximum temperature 62°) were freeze-dried and analysed for water-soluble solids, glucose, lipids, total and soluble nitrogen. Mouldy hay contained less of all these constituents than good hay; particularly glucose, lipid and soluble nitrogen.

Samples taken at intervals up to 3 weeks after the wet hay was baled, during which time the mould developed, were also analysed to establish when the changes occurred; up to 9 days after baling the samples gave results for water-soluble solids, glucose, lipids, and soluble nitrogen similar to those of good hay, but after 9 days there were appreciable losses, which were associated with a rise in pH from 5·6 to 7·4.

The increase in acidity, which is characteristic of heating in hay, took place during the first 7 days, when the maximum temperature was reached and the pH fell from 6·5 to 5·5; the iodine values of the total lipids were little changed from 1 to 11 days after baling, indicating that the proportion of unsaturated compounds was not greatly affected during the heating period.

The greatest changes in chemical constituents of this hay occurred well after the temperature had reached its maximum value and had begun to fall, so it can be concluded that the organisms responsible probably differ from those causing the initial fall in pH associated with the rise and maintenance of temperature. (Festenstein, in collaboration with Bunce and Gregory.)

PLANT PATHOLOGY DEPARTMENT

P. H. Gregory

On 30 September Mary D. Glynne retired after 43 years on the staff of Rothamsted; she is continuing in part-time work in the Department. Her services to agriculture were honoured by the award of the O.B.E.

R. C. Sinha left after gaining the Ph.D. degree of London University, and is now research associate in the Botany Department of the University of Illinois. The following joined us as temporary workers: P. Babos (Birmingham and Mytilene), M. V. Carter (Waite Institute, Adelaide), R. C. Close (Christchurch, New Zealand), R. Kisimoto (Zentsuji, Japan).

A. Kleczkowski attended the 3rd International Congress on Photobiology, Copenhagen, and spent six weeks at Wageningen at the invitation of the late Professor T. H. Thung. B. Kassanis, B. D. Harrison and A. J. Gibbs attended the 4th Conference on Potato Virus Diseases at Brunswick. B. Kassanis was also invited to lecture by the Board of the Agricultural University of Wageningen. B. D. Harrison spent two weeks in Portugal studying virus diseases of the grape-vine. E. W. Buxton was seconded for one year to the United Fruit Company Central Research Laboratories, Norwood, Mass., and spent some time visiting banana plantations in Central America. J. M. Hirst visited New Zealand at the invitation of the Department of Agriculture to advise on research into the ecology of the fungus causing facial eczema in sheep. On his return journey he visited the New South Wales Department of Agriculture, and the Rubber Research Institutes at Kuala Lumpur, Malaya, and Agalawatta, Ceylon.

Viruses and Virus Diseases

Disaggregation and reaggregation of tobacco mosaic virus protein

When purified protein from tobacco mosaic virus (TMV) is disaggregated at pH values over 6·5 it behaves like a mixture of at least seven different antigens. But when reaggregated at pH values below 6·5 it behaves as a serologically homogeneous material, as shown by gel-diffusion precipitin tests, and also by qualitative and quantitative precipitin tests in liquid. Some workers have claimed that a determinant is lost when the virus is broken up into protein and nucleic acid, and is regained when the protein is reaggregated into virus-like particles; although these claims seemed to be supported by some results obtained in the early stages of this work they were finally not confirmed. This cannot, however, be taken as conclusive evidence against the loss and gain of an antigen, because results may depend on the quality of the antiserum used in the tests. (A. Kleczkowski.)

Interaction of viruses

Components of tobacco necrosis virus. The " Rothamsted culture " of tobacco necrosis virus is unique among spherical plant viruses because it consists of large and small particles whose relationship was not understood. We now find that the two sizes of particle are two serologically unrelated viruses, with the peculiar relationship that, whereas the large particles multiply unaided, the small particles multiply only in the presence of the large ones.

Some of the single-lesion isolates from the " Rothamsted culture " gave only large particles, but none gave small particles only. The small particles were separated from the large by centrifuging partially purified preparations in sucrose gradient columns. Three light-scattering zones usually formed during this centrifugation: the top contained the small particles (21 mμ diameter), which alone were not infective, the middle zone contained the large particles (28 mμ), which alone were infective, and the bottom zone (when formed) contained small particles aggregated in groups of twelve. When inoculated together with the large particles, the small particles from the top zone multiplied and the lesions were smaller than those produced by the large particles alone. The number of small lesions produced depended on the ratio of small to large particles in the inoculum. (Kassanis and Nixon.)

Potato aucuba mosaic virus. The twelve strains of potato aucuba virus studied differed in their ability to be transmitted by *Myzus persicae*. No strain was transmitted from plants infected with this virus alone, but some strains were transmitted readily and others occasionally from plants which were also infected with either potato virus A or Y. Some strains were transmitted only from plants also infected with potato virus Y. Although the concentration of potato aucuba mosaic virus in the host is influenced by the presence of viruses A or Y, there is no correlation between its concentration and its transmissibility by aphids. (Kassanis.)

Tissue cultures

When grown under light for 18 hours daily in media containing 2% sucrose, cultures of " tobacco conditioned callus tissue " are white, but when the sugar in the medium is gradually decreased to 0·25% they become green. The phenomenon is reversible; the greenness disappears when the tissues are recultured in high sugar concentration. Tissues infected with tobacco mosaic virus, which had been kept for many years at 2% sugar, become green and their virus content decreases after a few recultures in media containing little sugar. (Kassanis.)

Lucerne mosaic virus

Purified preparations of lucerne mosaic virus contain bacilliform-like particles, quite unlike any other known virus in shape and apparent structure. Electron micrograms of mounts in neutral phosphotungstate show particles 18 mμ wide and of various lengths. All particles had the same electrophoretic mobility, serological specificity and nucleic acid content, but they differed in their sedimentation rates. Most of the particles were either 36, 48 or 58 mμ long,

and correspond with the components having sedimentation rates of 73 s, 89 s and 99 s reported by other workers for this virus. There was no evidence that particles of different lengths differed in infectivity. (Gibbs, Nixon and Woods.)

Three strains of lucerne mosaic virus were isolated, and all were transmissible by *Myzus persicae, Neomyzus circumflexus* and *Acyrthosiphum pisum*. Two of these (strain I avirulent and II necrotic to *Nicotiana xanthi*) caused necrotic local lesions when manually inoculated to French bean var. Prince. Strain III produced necrotic ringspots on *N. xanthi* and systemic symptoms instead of local lesions on bean. *M. persicae* was more successful than *A. pisum* as a vector of strain II, and both vectors transmitted best when given a period of fasting followed by 2 minutes' feeding on infected leaves. (Attafuah.)

Potato virus diseases

Paracrinkle virus in King Edward potatoes. In a survey for paracrinkle virus in commercial stocks of King Edward potatoes all tubers tested proved to be infected, some with paracrinkle virus alone, and some also with potato virus S. The strains of paracrinkle virus differ in virulence towards the variety Arran Victory and in their ability to be transmitted by *Myzus persicae*. Aphid-transmitted strains were common in all the commerical stocks of King Edward tested.

The virus-free stock of King Edward, produced by excising the apical meristem of a potato sprout as reported in 1955, has been increased in Northern Ireland by the National Institute of Agricultural Botany, and stocks are now large enough to start supplying potato-seed growers. In 1958 the virus-free stock was compared with seven commercial stocks in a trial organised by Mr. J. C. Cullen in different parts of England and outyielded them on average by 10%. (Kassanis.)

Control by insecticides. In co-operation with the Insecticides Department a trial was started at Efford Horticultural Station, Lymington, on the control of potato leaf and rugose mosaic by insecticides, including one (a granular formulation of "Rogor" prepared by Pest Control Ltd.) applied to the soil. Their effects on virus spread will not be known until tubers from the plots are grown in 1961, but the soil insecticides kept the plants free from aphids throughout the growing season, whereas a DDT spray did not. Aphids will be reared in the spring on tubers from the treated plants to detect any insecticidal residues. (Heathcote and Burt.)

Effect of age of infector on virus spread. Pots containing young potato plants infected with leaf roll or Y viruses were sunk in ridges of a potato crop (replacing healthy plants) at the end of May. In mid-July and mid-August they were moved to new sites, and at the same time younger infected plants were exposed at other sites. Tubers from the initially healthy plants adjacent to each infector were taken to detect spread of virus. Many plants adjacent to infectors exposed from 26 May to 14 July became infected, 83% with leaf roll and 78% with virus Y (including 6% leaf roll and 25% Y acquired from sources other than the adjacent infector). As in

1957, viruses spread little later in the season, regardless of the age of the infector plants. (Heathcote.)

Soil-borne viruses

Arabis mosaic virus. The ecology of the nematode vector, *Xiphinema diversicaudatum*, in relation to outbreaks of arabis mosaic virus, was studied in collaboration with R. D. Winslow (Nematology Department). The highest populations of the nematode were found in soil from woodlands and hedgerows. The virus was isolated from wild trees, and an outbreak in strawberry was seen on land newly taken into cultivation. Arabis mosaic virus was obtained from almost all sites where *X. diversicaudatum* was found, but the proportion of infective nematodes at different localities varied greatly. Males, females and larvae could all transmit the virus, and adults transmitted after being denied access to plants for a few weeks, indicating that the virus persists for long periods in the nematodes. (Harrison.)

Tomato black ring virus. Further work, in collaboration with the Scottish Horticultural Research Institute, showed that field outbreaks of the beet ringspot strain of this virus in raspberry and strawberry are associated with the presence in soil of the nematode *Longidorus elongatus*. The virus was transmitted to sugar-beet and spinach seedlings by larvae (but not by adults in the few experiments when they were tested separately) of *L. elongatus* hand-picked from virus-infested soil. (Harrison.)

Tobacco rattle virus. Sandy soil, taken from a field of potatoes severely affected by spraing disease, proved to be infested with tobacco rattle virus, which is thought to cause the disease. In tests with nematodes extracted from this soil, the rattle virus was transmitted by *Trichodorus primitivus*. (Harrison.)

Carrot motley dwarf virus

Many samples of carrots with " purple top " from different parts of England were tested, and all contained carrot motley dwarf virus. Previously we had been able to transmit the virus mechanically only after it had been transmitted by aphids to some host outside the *Umbelliferae*. We now find that it is transmissible from carrots by manual inoculation provided the clarified sap is buffered at pH7; it is also transmissible in water–phenol extracts that presumably contain mostly virus nucleic acid. The infection end-points with both kinds of preparation are around 1/1,000. (M. A. Watson, Sinha and Serjeant.)

In a field experiment at Woburn spraying with " Metasystox " on 13–14 June and again on 4 July decreased infection of carrots with motley dwarf virus by 21% and increased yield of roots by 2·02 ± 0·526 tons/acre. An earlier spraying on 26 May, soon after germination, had no effect (the virus entered the crop much later than in 1959, when all spray treatments were given too late). The vectors (*Cavariella aegopodiae*) migrated in large numbers from the beginning of June onwards, but were slow in establishing on the plants, probably because of heavy thunderstorms. Plant number, and apparently plant nutrition, varied across the experimental area, but had no effect on percentage infection or yield of roots; 75% of

the variance in total fresh weight was accounted for by the regression on the percentage of plants infected. (M. A. Watson and Serjeant.)

Barley yellow dwarf

When the virulent barley yellow dwarf virus " B " (which inhibits flowering and is transmissible by *Rhopalosiphum padi*, *Sitobium avenae* and *S. fragariae*) was inoculated to oat seedlings, together with the avirulent strain " X " (which does not alter plant habit, is transmitted only by the *Sitobium* spp., and produces characteristic red discoloration of foliage), the two viruses remain together in the plants for at least 3 months, and could be isolated by their vectors with little change in their proportions. But when the two viruses were inoculated to the plants in succession—one 14 days after the other—the first virus introduced gradually established supremacy over the other and, though they could be re-isolated easily within 30 days of the second inoculation, the challenging virus was rarely obtained after 60 days, even if it was the more virulent virus and had produced symptoms.

Rhopalosiphum padi, which was unable to transmit the original " X ", could transmit avirulent viruses resembling " X " from plants with mixed infection. These avirulent forms came particularly from plants infected by *S. fragariae* that had fed on a leaf infected with both viruses. (M. A. Watson.)

True broad bean mosaic

Plants infected with this seed-borne virus were found in crops of broad beans in several places in southern England. Most crops had 0·1% or less of plants infected, but a few crops had up to 10%. The spatial distribution of infected plants in the field, and the time of appearance of the symptoms, suggested that all the primary infections were from the seed, which is imported principally from North Africa. In late-sown crops secondary spread was observed over distances of 25 yards. Broad bean plants infected late in the season yielded as much seed as healthy plants, but early infection decreased the number of pods per plant and lowered the yield of seed by 20%.

Purified preparations of the virus contained " spherical " particles about 28 mμ in diameter, similar in appearance to those of the soil-borne ringspot viruses or red clover mottle virus. An antiserum prepared against true broad bean mosaic did not react with any of these viruses. Attempts to transmit the virus by *Xiphinema diversicaudatum*, *Ditylenchus dipsaci* (giant race) and *Sitona* spp. failed. (Gibbs.)

Spread of legume viruses in field bean crops

Use was made of experiments by M. J. Way (Insecticides Department) at Rothamsted and Woburn to compare the natural spread of legume viruses in plots of field beans sown at widely different seed rates. Results resembled those obtained in 1959. There was no significant difference between the number of virus-infected plants in insecticide-sprayed and unsprayed plots. Infection decreased with increased seed rate: for example, at Rothamsted on 27 June,

plots sown with 50 lb./acre had 2·7% plants with leaf-roll, and plots sown with 600 lb./acre only 0·1% leaf-roll. Leaf-roll, caused by a persistent virus, was the commonest disease early in the season, but the " non-persistent " mosaic virus spread later in the season. (Heathcote.)

In an experiment at Rothamsted with field beans sown on three occasions, 9 March, 27 April and 3 May, leaf-roll spread early in the season and mosaic later, the number of infections increasing with later sowing dates. Some rows were regularly treated with demeton methyl without affecting virus spread. Losses of yield depended on time of infection; early infection by leaf-roll decreased yield by over 75%, but late infection with mosaic had no appreciable effect. (Heathcote and Gibbs.)

Fungi and Fungus Diseases

Diseases of cereals

The six-course rotation experiment. In this experiment, begun in 1930 and ended in 1960, six crops were grown each year in the sequence: potatoes, rye, sugar beet, barley, clover, wheat. Annual surveys in winter wheat (variety Yeoman) in the last 24 years showed a trace of take-all (*Ophiobolus graminis*), with an annual mean of less than 1% of plants with lightly infected seminal roots. Eyespot (*Cercosporella herpotrichoides*) occurred each year, more than half the straws being infected in 5 out of 20 years (1938–57) (whereas in the four-course rotation experiment—potatoes, barley, ryegrass, wheat—this level was reached in 9 of the same 20 years). Eyespot was least in 1947 (2·3%), and most severe in 1958, when 98·7% of the straws were infected so that the entire crop lodged. In the few years when lodging occurred it was associated either with unusually severe eyespot or high yield of straw.

Barley and rye both became lightly infected by eyespot, but had fewer infected straws and fewer severe lesions than winter wheat. The disease appeared to have a negligible effect on barley and rye, though both helped to carry it through the rotation to subsequent crops. (Glynne.)

Effect of previous crops on winter wheat. Effects of date of sowing, seedrate and nitrogen were compared in two adjacent experiments in which Cappelle wheat was grown after two non-cereal crops (beans and potatoes) and after three cereal crops (spring wheat, barley, winter wheat). Sown at 2 and 4 bushels/acre on 2 October, 21 October, 23 November and 18 December, yields of wheat after potatoes were respectively 51·4, 46·0, 47·6 and 47·7 cwt/acre, with 34, 79, 60 and 20% of their areas lodged and with very little eyespot or take-all. Wheat following wheat, however, yielded only 32·1, 33·3, 34·6 and 33·0 cwt./acre, and in May about 34% of the plants were affected by take-all and 20% by eyespot. Seedrate had no effect on mean yields, but in both experiments the optimum seedrate depended on the sowing date; 4 bushels/acre yielded significantly less than 2 bushels at the second sowing, but more than 2 bushels at the last sowing.

Increase in the amount of nitrogen applied as " Nitro-Chalk " in spring from 0·46 to 0·92 cwt.N/acre had no significant effect on

yield of wheat after potatoes, and increased the area lodged from 33 to 64%. But the extra nitrogen added 6 cwt./acre to the mean yield of wheat after wheat, with no lodging; the effect was greatest in the plots sown on 2 October and at the lower seedrate. (Glynne and Slope.)

Effect of missing rows on non-parasitic lodging. Cappelle wheat was grown on fertile land which had been freed from the fungi causing eyespot and take-all by growing non-susceptible crops for two years. The drill was set to sow 2 and 4 bushels (R1 and R2) seed/acre at 7 inches spacing with all rows sown (D1), one row in four blocked (D3) and alternate rows blocked (D2). "Nitro-Chalk" was applied in spring at 0·5 (N1), 1·0 (N2), 1·5 (N3) cwt. N/acre. A clear pattern of lodging was apparent by the third week in June, when 84% of the area was lodged in D1 R2 N3, about half that area in D1 R2 N2, D1 R1 N3 and D3 R2 N3, so showing a similar decrease in lodging produced by omitting one dose of N, by halving the seedrate, or by missing one row in four. There was then little lodging in other plots, but prolonged wet weather, which delayed harvest till 31 August, led to lodging in all plots and decreased yield to an average of only 37·1 cwt./acre. Each dose of nitrogen increased lodging and decreased yield. Four bushels of seed produced less grain, with more lodging, than 2 bushels. The highest yield, 43·8 cwt./acre, was obtained with all rows sown at 2 bushels/acre, with least nitrogen. At this seedrate missing rows lowered yield, and missing two rows yielded less than missing one. When sown at 4 bushels, missing rows had little effect on yield at N1 and N2, but at N3 missing rows increased yield, D1, D3, D2 yielding respectively 30·3, 36·6 and 36·0 cwt./acre. D3 sown at 2 bushels yielded less than D2, but sown at 4 bushels yielded more. With a seedrate of 2 bushels/acre, 7-inch spacing yielded about 3 cwt./acre more than 14-inch spacing, but the effect of the wide spacing was lessened by increasing the amount of nitrogen. (Glynne and Slope.)

Broadbalk, 1960. On plots 2B, 3 and 7, the 1st, 2nd, 3rd, 4th and 9th consecutive wheat crops after 1 year fallow had respectively: 70, 51, 81, 79 and 47% straws with the eyespot fungus, of which 35, 28, 56, 54 and 26% had severe lesions; 0, 11, 17, 27 and 21% straws had take-all on the roots. It is difficult to explain the unusually high incidence of eyespot in the first crop after fallow, especially as at the end of March the same crops had only 4, 10, 26, 20 and 14% plants with eyespot. (Cox.)

Studies of soil microflora are being continued to explain the unexpectedly small amount of take-all on Broadbalk despite continuous cropping with wheat. No correlation was apparent between the total numbers of fungi or bacteria in either the soil or rhizosphere, and the incidence of take-all in the Broadbalk, Wheat and Fallow, and Cereal–Beans experiments. The low incidence on Broadbalk seems to be caused by factors preventing the development of the disease *after* infection has taken place. On the unmanured plot of Broadbalk, 21% of plants were infected on 28 March in the fourth successive wheat crop, but at harvest only 19% straws showed any crown-root infection. By contrast on the 4th wheat crop in the Cereal–Beans experiment, 59% of plants were

infected on 5 April, and at harvest 73% of straws had severe crown-root infection. The numbers of infected roots per plant were 1·5 on Broadbalk and 1·9 on the Cereal–Beans Experiment at the end of March, but 1·8 and 4·1 respectively at the end of May. (Cox.)

Cereal–Beans rotation. In the fourth and final year of the first series of this experiment, Cappelle winter wheat was grown after the following crop sequences: W Ws W, B W B, sW W sW, O W sW, W O sW, and W O Be (using the abbreviations: W = winter; sW = spring wheat; B = spring barley; O = spring oats; Be = winter beans). After these respective sequences plots yielded 27·5, 34·2, 26·8, 25·0, 20·0 and 49·9 cwt. grain/acre; they had respectively 77, 63, 79, 85, 87 and 7% of straws with take-all at harvest. Two years with the non-susceptible crop, oats and beans (sequence W O Be) nearly eliminated take-all, and wheat after this sequence yielded twice as much as after a susceptible crop. However, growing a non-susceptible crop of oats in 1957 and 1958 (sequences O W sW and W O sW) had no beneficial effect in 1960—in fact, there was more take-all and less yield after these sequences than after continuous wheat.

Eyespot was not prevalent; its incidence was less than 10% after all these sequences, and less than 1% after oats–beans. The incidence of Sharp Eyespot was unusually high (mean 59·3% of straws infected), but there was no difference between the six crop sequences. (Slope.)

Cephalosporium stripe. In mid-June occasional wheat plants with yellow-striped leaves were found in several field at Rothamsted. Dr. L. J. Tyler (visiting from Cornell University) diagnosed the symptoms as stripe caused by *Cephalosporium gramineum*. A *Cephalosporium* was isolated from affected leaves, nodes and internodes, but the isolates have not yet been tested by inoculation. (Slope.)

Potato diseases

The study of how potato blight epidemics originate, of haulm resistance and of control by spraying, have all stressed the need for more information about tuber infection and the activity of *Phytophthora infestans* in soil. This has now become a major aim of our work, and the weather of 1960 was unusually suitable for the study.

Development of potato blight in 1960. The first 3 months after planting were warm and dry and potatoes grew slowly. After the end of June frequent rain encouraged rapid growth of haulm and tubers, so that yields were potentially high, despite tubers forming somewhat late. Blight was first found occurring naturally in an invaded stem on a King Edward plant in a spraying experiment on 24 July, by mid-September the haulm was completely killed. Zineb (Z) or copper oxychloride (C) were applied on four dates (14, 25 July, 13, 27 August). The total yield from spray with an early application of Zineb (Z, C, C, —) was 18·46 tons/acre, compared with 14·43 tons/acre from unsprayed plots (—, —, —, —). Plots with sprays (—, C, C, —) and (—, Z, C, C) yielded respectively 16·66 and 16·76 tons/acre. Initially there were large differences between treatments in tuber infection, but these differences

eventually disappeared with just over 25% of tubers infected in all treatments. (Hirst and Stedman.)

Effect of nitrogenous fertilisers on blight. An unsuccessful attempt was made to confirm Lowings's (*Trans. Brit. mycol. Soc.* 1959, **42**, 491–501) observations of how the amount and timing of nitrogenous fertilisers may affect the development of potato blight. Unsprayed Majestic plots received similar treatments to those used by Lowings, but differences in the rate the foliage was destroyed were small and inconsistent, and they seem unlikely to have had any effect on yield or to offer hope of a useful and reliable control practice. (Hirst and Stedman.)

Haulm and tuber resistance to Phytophthora infestans. In a field experiment the haulm resistance of Pimpernel (the most resistant commercial variety in laboratory tests in 1959) was compared with Ackersegen, Majestic and Arran Viking. Majestic and Arran Viking leaflets were half killed 15 days sooner than comparable leaflets of Pimpernel and ten days sooner than Ackersegen. Pimpernel was defoliated more slowly because leaflets were infected more slowly and also died more slowly after infection. Sporulation differed significantly on the four varieties: the mean width of the sporing annulus, measured in the field for 13 days, was 3·2, 2·1, 1·7 and 1·1 mm. for Majestic, Arran Viking, Ackersegen and Pimpernel respectively.

Work was begun to assess the acuracy of estimating haulm resistance from a single chemical test—peroxidase activity. Of 41 clones tested the 10 Mexican selections of Niederhauser, reported to have high levels of " field resistance ", had the greatest peroxidase activity.

In laboratory tests wound-free tubers (grown in peat overlying soil in large porcelain pots) were infected through eyes and lenticels by spraying the tuber surface with inoculum. Preliminary tests showed that Arran Banner and Ulster Ensign were more readily infected by this method than Up-to-Date and King Edward, and that infections on Arran Viking and Majestic tubers were often arrested at an early stage.

Infection of tubers in the field was studied in plots of the tuber-susceptible varieties Up-to-Date, King Edward, Arran Banner and Ulster Ensign, arranged in a 4 × 4 Latin square. Two rows of Majestic, planted between each column of plots, were inoculated on 4 July to ensure that blight arrived in all plots at the same time. Samples were taken each week from predetermined areas within plots and tested in two ways. The tubers were lifted at once from half the plant; the haulms were removed from the other, when the ridge was covered with " Polythene " sheeting and the tubers allowed to " incubate " for 5 days in the ground before lifting. The first blighted tubers were found in the " incubated " samples of all varieties lifted on 3 August; these must have become infected when less than 5% of the haulm was blighted. The numbers of infected tubers from later samples increased after periods of rain, and most new infections occurred after rain which fell when the haulm was about 50% defoliated.

Most infections on Arran Banner, King Edward and Up-to-Date occurred at the rose end or on the body of the tuber, and were

associated about equally with eyes or lenticels (though in King Edward the eyes were invaded rather more often than lenticels). On Ulster Ensign most infections were in lenticels on the body of the tuber. During the epidemic the fungus was found sporing from lenticels and eyes of blighted tubers of these varieties while still in the soil.

Blight susceptibility of haulm and tuber in different genotypes. In co-operation with the John Innes Institute, the differential reactions of haulm and tuber were studied in genotypes based on genes R1, R2, R3 and R4 to six races of *Phytophthora infestans.* The races either caused a hypersensitive reaction on leaves of the clone or could infect and spread in their leaves. Gene R1 conferred to the tuber a hypersensitivity comparable with that in the leaves, whereas genes R2, R3 and R4 often did not. Races giving a hypersensitive reaction in the leaves of R2, R3 and R4 clones grew in the tubers, although more slowly than in clones without these genes. Tubers of most clones, except Orion (R1) and Reaal (R1R3), were highly susceptible, often more so than King Edward, to races of the fungus which could spread in their leaves. (Lapwood.)

Activity of Phytophthora infestans *in soil.* Unless haulm is destroyed very early, usually with some sacrifice of yield, a proportion of growing tubers usually becomes blighted in the soil. A method of assessing the concentration of *P. infestans* spores in the soil is needed to study conditions and routes by which tubers in soil are infected from the haulm. Plating soil dilutions on media containing antibiotics proved unsatisfactory, as did attempts to separate sporangia by preferential movement in an oil/water emulsion. The use of tuber-tissue as a selective medium to " bait " the fungus out of soil is a promising method. Slices 5 mm. thick from washed tubers are covered with 0·75 ml. of soil, wetted and stored in humid chambers at 20°. After 24 hours each slice was cut radially into octants, and a week later octants bearing sporangia of *P. infestans* were counted. The method was calibrated with soil to which known numbers of sporangia had been added. After applying the multiple-infection transformation, there was a significant linear relation between the number of spores per slice and the number of octants infected; 1,000 sporangia/slice caused about 150 infections per 100 octants (or about 78% infection); 50% of the octants were infected by about 500 sporangia/slice. The method should be capable of detecting as few as 10 sporangia/ml. of soil.

In 1960 the technique was used to estimate spore concentration at various depths from the crest of the ridge beneath Majestic potato plants with blight on the haulm. When approximately half the crop had been destroyed the concentration was estimated at 2,000/ml. in the surface soil, 440 at 2 inches and 50 at 4 inches. (Lacey.)

Aerobiology

Black rust of wheat. The number of airborne *Puccinia graminis* uredospores within spring wheat crops often increased at the start of, or an intensification of, rain. Similar behaviour has been noticed previously for spores of *Cladosporium.* (Hirst and Stedman.)

Release of ascospores during dew. Reports on the importance of

wetting by dew in release of ascospores of certain Pyrenomycetes are conflicting. To assess " dew-release " of ascospores of *Mycosphaerella pinodes*, about 50 g. of dry pea haulm, heavily infected during summer of 1960, was placed on a frame carried upwind of the orifice of a Hirst spore trap (from which the rain-shield had been removed) and exposed repeatedly to dews during the autumn. Dew records were made with a Surface Wetness Recorder Mk. III beside the spore trap. With the sample 0·5 m. above ground level, and between 10 and 50 cm. from the trap orifice, ascospores were caught on each of eight nights when a full-scale dew reading was shown on the Wetness Recorder. Release began when the trace was half-way up the scale, usually reached a maximum some 3 hours later and declined to zero during the next 6 hours—usually before drying had begun.

The rainfall equivalent to a half-scale deflection is calculated as 0·009 inch. (The amount of rain required to produce measurable ascospore release from the perithecia of *M. pinodes* in wind-tunnel tests at the Waite Institute, Adelaide, has been estimated as 0·007 inch.) (Carter.)

Calibration of whirling-arm air sampler. The Perkins " Rotorod " sampler is claimed to be over 90% efficient for collecting airborne particles in the 20-μ range. A sampler of this design, powered by a 6-volt E.M.I. motor, was calibrated in the wind-tunnel against the isokinetically operated Cascade Impactor with ascospores of *Mycosphaerella pinodes* (12–15 × 6–8 μ). In a turbulent air-stream efficiency depends on wind speed and varies from 50% of Cascade Impactor efficiency at 1–2 m./sec. to 90% at 4–5 m./sec.

In similar tests with spores of *Lycopodium clavatum* (30 μ) the rod sampler showed a maximum of 80–85% efficiency at 1·5 m./sec. Efficiency declined with increasing wind speed to 60–65% at 9 m./sec. Comprehensive tests with a range of spore sizes are clearly needed so that the " Rotorod " sampler can be used in the field. (Carter.)

Clubroot of Brassicae

In attempts to free *Plasmodiophora brassicae* from contaminating organisms to facilitate physiological studies, young galls were incubated temporarily in solutions containing penicillin and streptomycin in high concentration, and, after washing, inoculated at various dilutions to young cabbage seedlings. After a week the plants were transferred to meat infusion for a few days to detect contaminants. A small proportion of apparently bacteria-free seedlings, each with a few root hair infections, was occasionally obtained. So far, however, a contaminant-free club has not been grown, apparently because of the difficulty of growing enough good plants aseptically. (Macfarlane.)

Fusarium wilt of peas

F^4 lines derived from the second back-cross between the garden pea varieties Greenfeast (syn. Lincoln) and New Era, brought from the Waite Institute, South Australia, were grown at Coggeshall, Essex, in a field heavily infected with *Fusarium oxysporum* f. *pisi* race 1. Of seven lines selected for homozygosity of resistance to South

Australian race 2 of the wilt fungus, six were fully resistant at Coggeshall, and a seventh showed a uniform partial wilting.

An F2 population of 99 plants from the above cross, inoculated in the glasshouse during the summer with an isolate of race 1 taken from wilted Onward plants at Coggeshall, failed to segregate any susceptible plants, although Onward control plants wilted readily. This suggests that the parental strain of Greenfeast (selected in New Zealand for resistance to race 1) shares with New Era a common or closely linked gene for resistance to this race of *F. oxysporum* f. *pisi*. (Carter.)

Variation in Verticillium albo-atrum

The investigation of genetic recombination in *Verticillium albo-atrum* was continued. Using nutritional markers and differences in acriflavine tolerance showed that recombinant genotypes were produced much more frequently than usually observed in other imperfect fungi. Conidia of *V. albo-atrum* are almost always uninucleate, so that novel genotypes formed during development of a colony were readily detected by determining the phenotypes of the spores which the colony produced.

About one per million of the conidia produced in a mixed culture of two complementary auxotrophic strains were prototrophic. These were later shown to be prototrophic, because they contained heterozygous diploid nuclei and the nutritional requirements were recessive to their respective wild type alleles. The selected diploid nuclei were heterozygous at four loci. Samples of conidia harvested from 10-day-old cultures initiated by single heterozygous uninucleate conidia contained fourteen of these sixteen possible classes.

The two remaining classes were not found in a random sample of 2,000 spores isolated directly from cultures segregating for all four markers (i.e., among first-order segregants). However, about 2% of these first-order segregants were still heterozygous with respect to one or more of the marked loci, and a sample of over 2,000 conidia from heterozygous first-order segregants included many spores with the phenotypes not found previously. This delay in the production of certain recombinant classes can be interpreted as an effect of genetic linkage, and the evidence gathered from the analysis of heterozygous first order-segregant nuclei indicated that the four markers were located in one linkage group.

Reciprocal phenotypes tended to be produced as often as expected if the recombinant genotypes were produced at meiotic divisions. However, this expectation was not supported by a further statistical analysis, and the recombinants were probably produced at irregular mitotic divisions as in the parasexual cycle.

V. albo-atrum occurs naturally in two colour forms. Most isolates produce black torulose hyphae, but strains unable to do so are often isolated from them. Previous work (*Rep. Rothamst. exp. Sta.* for 1959) suggested that cytoplasmic factors are involved in the inheritance and/or expression of the black character. The heterozygous lines selected for studying genetic recombination were established by mating black and white hyaline auxotrophs. These heterozygotes, and over 5,000 isolates from them, all formed some black torulose hyphae on augmented prune extract agar medium,

and none was identical with the hyaline parent. Therefore, the colour difference was not determined at a single chromosomal locus. Although the evidence does not exclude the possibility of it being inherited as a polygenic character, cytoplasmic factors affecting expression and perhaps inheritance still need to be invoked.

The development of black hyphae depended strikingly on incubation temperature. Heterozygous isolates, and recombinants derived from them, were examined after incubation for 2–3 weeks at 23°, 20°, and 15° on augmented prune extract medium. The optimum temperature for growth of *V. albo-atrum* on this medium is 23°, and all isolates so tested formed intense black hyphae, whereas all replicates at 20° were hyaline. The cultures at 15° contrasted with the previous two series in showing, with one exception, enormous variation in colour between replicates of each isolate. The exceptional isolate was a single auxotroph requiring only adenine, and this was the nutritional phenotype of the original black parental culture. All replicates of this isolate incubated at 18° were black. These observations do not allow any conclusion to be drawn about the inheritance of the colour difference, but emphasise the need for a precisely defined environment for determining an isolate's capacity to produce black hyphae.

The two auxotrophs crossed in studying genetic recombination were both derived from parental strains causing fluctuating hop-wilt, but none of the recombinants tested showed enhanced virulence towards hops of the variety Fuggle. Only one of the parental strains wilted tomatoes (variety Klondine Red), and this only mildly, but a few of the stable prototrophic recombinants recovered from the unstable heterozygous lines caused much more severe wilt in tomato. (Hastie.)

Mycofloral succession in hay

During 1960 hay was again baled experimentally at different moisture contents to study the mycofloral succession. Attention was concentrated on hay with the kind of moulding previously found to be associated with " farmer's lung ". Hay from Great Field, baled at a moisture content of 46%, behaved in the same way as hay from New Zealand Field in 1959 which had been baled with 42% moisture. The temperature rose to 60° in 3 days, by the 11th day it was still 55°, but by the 21st day it had fallen to 20°, after which it remained more or less steady near the mean air temperature. The moisture content fell gradually from the start, and by the 16th day it had reached 20%. During this period the mould content increased to about 10 million spores/g. dry weight of hay, and the bacteria and actinomycetes increased to over 100 million spores/g., conspicuous among which were thermophilic actinomycetes growing at 60°. The pH rose from about 5·5 to 7 as the hay became very mouldy with a whitish covering consisting mainly of actinomycete spores. (Gregory and Bunce.)

Sitka-seedling diseases

The effects of treating seed and soil in various ways on numbers and sizes of Sitka spruce (*Picea sitchensis*) were investigated at five Forestry Commission nurseries where the incidence of disease varies

greatly. (See Reports of Chemistry and Insecticides Departments.) Treating seeds with TMTD, "Captan" and an organo-mercury compound sometimes increased the numbers both of germinating seedlings and survivors, but did not affect their mean heights. In contrast, partial soil sterilisation with formalin and chloropicrin did not increase the numbers of seedlings that emerged but increased the numbers of survivors and their mean heights.

In an attempt to identify the causes of these effects, detailed analyses for fungi and bacteria were made at frequent intervals, of soil, of rhizospheres, of rhizoplanes and of diseased seedlings. Excepting *Trichoderma*, formalin and chloropicrin usually decreased the numbers of fungi in soil, including possibly pathogenic Phycomycetes and strains of *Fusarium*, but had little effect on their numbers in the rhizosphere.

Although soil sterilisation had little effect on the rhizosphere flora, it had, surprisingly, a big effect on the fungi, excepting *Fusarium*, isolated from the root surface-"rhizoplane". Both formalin and chloropicrin increased the frequency of *Trichoderma* and decreased the frequency of Phycomycetes. In addition, some Phycomycetes were fewer after seed treatment, suggesting, because the seed-coat is carried above ground by germinating seedlings, that the microflora of root surfaces may be determined at an early stage in development. (Ram Reddy and Last.)

NEMATOLOGY DEPARTMENT

F. G. W. Jones

F. G. W. Jones gave a paper at the Twelfth International Symposium on Plant Protection in Ghent; he also spent ten weeks in India, where he gave a course of lectures and practical work at the Muslim University, Aligarh, and visited other centres to advise on plant nematology. Miss K. Pawelska (Poland) joined the Department in March to work on problems associated with *Heterodera* spp. for one year. Mr. C. D. Blake (Australia) arrived in August and will spend two years working on host–parasite relationships in *Ditylenchus dipsaci*. Miss P. M. Nelson left in July and was replaced by Miss M. C. Gander. J. J. Hesling left in November to join the staff of the Glasshouse Crops Research Institute.

Systematics and Bionomics

The revised text of the late Tom Goodey's book *Soil and Freshwater Nematodes* is almost complete, but many drawings still have to be done. *Aphelenchoides cocophilus*, the nematode associated with " red-ring " disease of coconut, has been newly described from fresh material sent from Trinidad by Dr. D. W. Fenwick. Because of a combination of morphological characters, this nematode has been transferred to a new genus, *Radinaphelenchus*. While examining many genera and species in the Dorylaimoidea, new ideas were formed on the nature of the so-called spear guiding apparatus in this group. The old concept of the guiding ring as a single or double structure has often appeared rather arbitrary. The guiding apparatus is essentially a sheath fused outwardly as a fixed ring to the wall of the stoma in front and inwardly round the spear base near its junction with the spear extension. This sheath is also fused outwardly to the stoma wall about half-way down. As the spear is moved forwards an evagination of the sheath occurs in front of the fixed, anterior ring, and the end of this evagination is seen as a second ring. Thus, whether one or two rings are seen depends on the position of the spear relative to the head and the state in which the nematode is fixed when being mounted. In *Aporcelaimus*, which is said to have no ring, the double ring may occur when the spear is protruded. (Goodey.)

A study of several *Longidorus* populations from Great Britain showed that at least five species occur. One of these, often found in association with virus-infected plants, is *Longidorus elongatus* (de Man 1876) Thorne and Swanger 1936. The others are new species which are being described. (Hooper.)

Work continued on the Mononchidae of New Zealand. Hitherto unobserved structures have been seen in the region of the oesophago-intestinal valve, some of which disappear shortly after fixation, and this may be why published accounts of this region do not agree with the morphology of live nematodes. The oesophago-intestinal valves

of the Mononchidae are of two types; *Anatonchus, Iotonchus* and *Miconchus* have three conspicuous, hollow tubercles on the posterior end of the oesophageal lining near the funnel-shaped valve, whereas *Mononchus, Prionchulus, Mylonchulus* and *Cobbonchus* have no tubercles and the lining narrows near the posterior end. *M. truncatus, M. papillatus* and *P. muscorum* have been redescribed, the genera *Mononchus, Prionchulus, Iotonchus* and *Cobbonchus* have been reviewed, and several new species described. The Enoplida have been reclassified into seven suborders, mainly on the basis of the oesophageal glands and their ducts. The Alaimidae form a new suborder. The Mononchidae together with the new family Bathyodontidae (type genus *Bathyodontus* Fielding 1950) form the new superfamily Mononchoidea within the Dorylaimina. The life history of *Dioctophyme renale* indicates a relationship between the Dioctophymatina and the Gordiacea. (Clark.)

Work on *Meloidogyne* spp. dealt with the morphology and variability of natural and cultured populations. Some of the original type material used by Chitwood for his descriptions of *M. arenaria, M. arenaria* subsp. *thamesi* and *M. hapla* in his 1949 paper was obtained from America. The specimens are being compared with other populations of the same species. In conjunction with the study of field populations, artificially reared cultures were started to show the variability which can occur among individuals descended from the same female. For this work the foam agar technique developed by den Ouden at Wageningen has been adopted. The progeny from these inoculations are used to continue the particular line for further generations and to compare members of the same lines, different generations of the same line or different lines of the same population. The principal character used for identification is the cuticular pattern in the vulval–anal region. Photomicrographs were made of specimens from the type material and from one or two other populations for comparison with the types. By these various means it is hoped to improve descriptions of species.

A new root-knot nematode from Norfolk was described, the first indigenous species from Britain. *M. artiellia* n.sp. differs from the other known species in the posterior cuticular pattern, the stylet of the infective larva and the length and shape of its tail. It has been found in one locality only, on the roots of oats and brassicas. It also attacks barley, wheat, red clover, broad bean, pea, lucerne and *Medicago lupulina*. There has been no report of crop damage.

Root-knot diseased plants were received from Ghana, Nigeria, Sierra Leone, Libya and South Africa; from East Pakistan and India; from five counties in England and two in Scotland. The nematodes were usually either *M. javanica* or *M. incognita* (*sensu lato*). The British ones were all from glasshouses. One interesting sample of chrysanthemums from a glasshouse was infested with *M. hapla*, which is usually looked upon in this country as the " outdoor root-knot ", although it has also been found occasionally under glass. (Franklin.)

The experimental work done some years ago on how three parasitic nematodes, *Ditylenchus myceliophagus, Aphelenchoides composticola* and *Paraphelenchus myceliophthorus*, affect the growth and

yield of mushrooms, was published and is to be reprinted in the *Bulletin of the Mushroom Growers' Association*. (Goodey.)

Out of many samples of mushroom compost examined, a few contained *Aphelenchus avenae*, usually mixed with other nematodes parasitic on mushrooms. When *A. avenae*, raised in pure culture on mushroom mycelium grown on agar plates, were added to mushroom compost, the mycelium was destroyed and the nematodes multiplied, sometimes more than a thousandfold in 6 weeks on 25 g. of compost. Evidently *A. avenae*, a nematode often associated with diseased plants and known to be a fungal feeder, can be injurious to mushrooms.

Samples of vigorous and poor turf were received from the Sports Turf Research Institute. No particular nematode could be correlated with the disease, but both healthy and diseased lots had very high populations of *Tylenchorhynchus* and *Helicotylenchus*, and the roots of *Poa annua* were heavily galled by *Ditylenchus radicicola*. Terminal galls on the roots of *Agrostis* sp. contained *Pratylenchus pratensis*. In a replicated experiment fifty specimens of *Tylenchorhynchus dubius*, added to the grass, *Agrostis tenuis*, in 3½-inch pots at the time of sowing, yielded 45,000 specimens after 12 months, but the growth of the grass was apparently unaffected. (Hooper.)

Feeding Mechanisms

The structure of the oesophageal " valve " of *Pelodera* (*Cruznema*) *lambdiensis* and *Rhabditis* (*Cephaloboides*) *oxycerca* was studied by serial sections and by whole mounts of excised oesophagi containing heavily pigmented particulate " food ". A cinematographic technique was used to demonstrate the inter-relations of serial transverse sections.

By feeding nematodes on Indian ink and taking ciné films it was shown that, in rhabditids, the oesophageal lumen immediately behind and in front of the so-called " valve " forms the true valve mechanism. The " valve " itself, which appears to behave as a pump, is responsible for conducting food from the posterior end of the isthmus to the intestine. The " valve flaps " do not come into such close contact with one another that they function either as a valve or as a piston within the pump, and their significance is not yet understood. The pumping action is achieved by the postero-lateral walls of the chamber opening outwards, with the oesophago-intestinal canal (the " outlet valve ") closed. This creates a suction which works on food accumulated at the posterior end of the isthmus and draws some of it into the chamber. The anterior wall of the chamber and the " valve flaps " then move backwards, while the oesophageal lumen (the " inlet valve "), which passes through them, closes. The postero-lateral walls of the chamber now close inwards, thus tending to build up pressure within, but simultaneously the " outlet valve " opens and the contents of the chamber are expelled into the intestine.

In *Diplogaster* the median oesophageal bulb is the region where food particles are accumulated. (In rhabditids it is the anterior half of the isthmus where this occurs.) Food moves very rapidly down the isthmus to the posterior half of the second oesophageal

bulb, from which it is passed to the intestine by a wave of muscle action resembling that in the isthmus of rhabditids.

Attempts were made to study the feeding of several genera of spear-bearing nematodes. Film records at high magnifications were obtained of *Aphelenchoides ritzemabosi* feeding on mesophyll and epidermal cells of chickweed leaves. In comparison with *Aphelenchus avenae*, these showed a very gentle pulsation of the oesophageal bulb during the whole period that the spear was within the plant cell. Shortly after withdrawal of the spear, the bulb underwent three or four vigorous pulsations, possibly to clear the oesophagus of food.

Preliminary studies were made of the pH of the gut wall of two genera of nematodes, *Pelodera* and *Diplogaster*, which were cultured in nutrient agar mixed with neutral red or methyl red as pH indicators, both red at the lower end of their pH range and yellow at the upper. These dyes were absorbed into the gut wall in concentrations sufficient to show their colours distinctly in about 2 days. Neutral red always remained red, indicating that the pH never rose above 6·8. Methyl red showed that the region of the intestine of *Pelodera* immediately behind the front few cells usually had a pH below 5 while the rest of the gut was around 6. *Diplogaster* showed little consistency in the pattern of pH variation in the gut wall, although the range appeared similar to that of *Pelodera*. Where indicator dye was held in the oesophagus, as in one *Pelodera*, the pH was at least 6. (Doncaster.)

Predators of Nematodes

Further film records were obtained of predators of nematodes. Tardigrades, found feeding on free-living nematodes, were filmed, and these showed considerable tenacity when they attached themselves to large active prey. Small nematodes were sometimes drawn right into the mouth, others were held at some point along the body and gradually killed and fed upon.

Large predatory ciliate Protozoa (genus *Urostyla*?) which freely ingest nematodes were filmed and photographed with nematodes at various stages of ingestion, some showing the prey completely engulfed. (Doncaster and Hooper.)

Cyst-Forming Nematodes of the Genus *Heterodera*

Hatching factors

The joint work with A. J. Clarke (Biochemistry Department) on the chemical nature of hatching factors continued. Cyst stocks of the potato, beet and cabbage eelworms are being built up by extraction from field soils or by rearing on inoculated pot plants. Over 300 gallons of crude potato diffusate were produced in addition to 200 gallons of crude rape kale diffusate. Rape kale diffusate was also obtained from seedlings grown in 2-litre aspirators and leached by distilled water. This method produces a diffusate free from soil impurities, but quantities are small. (Nelson and Gander.)

The literature contains statements that leachings from grass

roots stimulate a hatch of potato-root eelworm eggs, but tests with diffusates from fifteen species of grasses were all negative. (Pawelska.)

Biotypes of potato-root eelworm (Heterodera rostochiensis)

Tests with thirty-nine populations of potato-root eelworm from the United Kingdom showed that 43% of the populations were mainly biotype A, 15% were mainly biotype B and the remaining 42% were mixtures of biotypes A and B. Both biotypes reproduce successfully on commercial potato varieties; A reproduces on resistant varieties bred from *Solanum multidissectum* but not on those bred from *S. tuberosum* and sp. *andigena*, whereas biotype B reverses this behaviour. A long-term experiment is under way on a field at Woburn, mainly infested with biotype A, to test the effect on the soil population of growing resistant *S. andigena* hybrids. Continuous cultivation of a resistant variety is being compared with continuous cultivation of some commerical varieties and with rotations which include the resistant variety and the variety Majestic in different proportions. (Jones and Pawelska.)

Cytology of Heterodera galeopsidis

Attempts were made to count the chromosomes of the Galeopsis eelworm, *H. galeopsidis*. The number is high, and may be the same as the somatic number, 27, in *H. trifolii*. No sperms were seen in the reproductive tract. Evidently the species is distinct from *H. schachtii*, which has the somatic number of 18 and usually has sperm in the reproductive tract. *H. galeopsidis* is probably triploid and parthenogenetic, like *H. trifolii*. (Hesling.)

Pea-root eelworm Heterodera göttingiana

Work is in progress on the bionomics of the pea-root eelworm, *Heterodera göttingiana*, in the field. After failing to stimulate larvae of this eelworm to hatch *in vitro*, hatch in soil under a pea crop was studied to find whether this species differed from others. The numbers of free larvae in the soil and in the roots of the pea crop grown in a small plot of infested soil were estimated at weekly intervals throughout the spring and summer of 1959, and from this the percentage hatch estimated. This was about 10% of the original egg content of the cysts at the beginning of the season, a small hatch compared with the calculated annual fall of 30%. This discrepancy is unexplained, but it may be because larvae die in the soil and in roots, or because of sampling errors and losses during extraction. In 1960, instead of attempting to assess hatch absolutely, the estimated hatch of pea, beet and potato-root eelworms were compared in soil under host crops, non-host crops and fallow. Pea-root eelworm and potato-root eelworm behave similarly, whereas beet eelworm under beet hatched less than the other two species under their respective host crops, perhaps because the beet grew poorly. In fallow soil beet eelworm hatched better than the others, as might be expected from the high hatch of the species in water.

This work confirmed that in field crops pea-root eelworm is stimulated to hatch by its host-plant roots. Moreover, it hatches

under a host crop at much the same rate as other species whose larvae are readily stimulated to emerge in the root diffusate of host plants *in vitro*.

In an experiment in microplots, a single variety of pea (Onward) was grown in soil containing different population levels of pea-root eelworm, and the effect of these differences on yield was examined. Onward is highly susceptible and produces a high population of eelworms. The yield of peas decreased strikingly with increase in initial population level; the sharpest decrease was at levels between 20 and 40 eggs/g. soil. At 80 eggs/g. soil both the yield of peas and the total yield of haulms and peas were only 50% of that at 10 eggs/g. soil. This suggests that the level above which it would be unsafe to grow peas is near 10 eggs/g., the same level the National Advisory Service has found to apply to beet and beet eelworm and to oats and cereal-root eelworm, whereas potatoes can tolerate more potato-root eelworm. (Shepherd.)

Weekly counts of the encysted egg population in pots of fallow soil, containing early- and late-sown peas, variety Kelvedon Wonder, showed that the population declined by about 30% between early March and mid-July under fallow. Decline was more rapid in the early part of the season under peas, confirming that host roots stimulate hatching. Population increase under peas first showed 13 weeks after sowing. Late-sown peas suffered greater injury than the early-sown ones. (Hesling.)

Another pot experiment was completed in which the effect of five inoculum levels was tested on three types of bean (*Vicia*) and three varieties of pea. (Hesling.) Further population studies are under way in collaboration with the Pea Growing Research Organisation. (Jones.)

Other work on cyst-forming nematodes included tests of the resistance of twelve breeding lines of sugar beet to the beet eelworm (Pawelska), and rotational experiments with potato-root eelworm (Doncaster).

Chrysanthemum Eelworm *Aphelenchoides ritzemabosi*

In experiments on varietal susceptibility, artificial infection of chrysanthemum cuttings destroyed the plants. Although late inoculation of clean plants in early August soon produced symptoms on the leaf inoculated, a month elapsed before the disease spread, and it was never severe. Thus, when plants are destroyed by eelworms in the autumn, the infestation was probably present at an early stage in the plant's life. Late infestations on resistant or less susceptible varieties may be overlooked and the stock may seem clean. These results stress the need to control eelworm in the chrysanthemum stool, but unfortunately experiments suggested that hot-water treatment is difficult to apply, and effective treatment of stools on a commercial scale is impracticable. (Hesling and Wallace.)

Three features of the infestation of leaves by chrysanthemum eelworm were studied: (1) the behaviour of the eelworms in the leaf; (2) the cause of browning in infested leaves; and (3) the differential resistance of chrysanthemum varieties to eelworm attack.

The length of the life cycle of the chrysanthemum eelworm is about 10–13 days. Each female lays about 25–35 eggs in compact groups, which take about 4 days to hatch; larvae become adult in 9–10 days. Egg laying is mainly confined to the boundary between the green and discoloured tissues, and adults are chiefly responsible for spreading infestations. Infested leaves turn brown more quickly as relative humidity and number of eelworms increase. Eelworms are the primary cause of browning, although discoloured tissues have a distinctive population of saprophytic fungi. Chlorogenic acid, isochlorogenic acid and a glycoside of luteolin are the main polyphenolic constituents of chrysanthemum leaves, and the first two are the major substrates for enzymic oxidation which gives the brown end-products. The polyphenols and the enzyme polyphenol oxidase in the leaf tissues meet when cells are pierced by the eelworms during feeding.

Infested leaves of resistant varieties brown quickly, and eelworm multiplication is inhibited. This hypersensitive reaction prevents further eelworm spread. There is no correlation between rate of browning in different varieties and polyphenolic content or polyphenol oxidase concentration. Infested leaves of resistant varieties turn brown sooner because the females move about more in the leaf, piercing hundreds of cells which subsequently turn brown, but the females lay few eggs. In susceptible varieties the females move very little, pierce few cells and lay many eggs. Neither polyphenols nor their oxidation products affect movement or egg-laying in the leaf. The primary cause of resistance in chrysanthemums to eelworm is undetermined, but it may be the lack of something essential to the nutrition of the eelworm. (Wallace.)

Ecology of Soil Nematodes

Rothamsted and Woburn Six-Course Rotations were sampled frequently. Nematodes were fewest from May to July, and spiral nematodes were very rare at Woburn, confirming results in 1958–59.

Broadbalk, Hoosfield, Barnfield and Parkgrass were sampled every three months. Barnfield, fallowed in 1960 after continuous mangolds, had the poorest nematode fauna, but yielded some interesting species. The different fertiliser treatments applied to the classical fields did not greatly affect nematodes, but pH differences from liming on Park Grass were associated with changes in the nematode fauna: *Pratylenchus* was more numerous on the unlimed half of each plot, *Aphelenchus* and Diphtherophoridae on the limed half. Seasonal variations in numbers of nematodes on Broadbalk and Hoosfield were similar to those on the corresponding plots on the Rothamsted Six-course Rotation. The classical wheat and barley plots on Stackyard, Woburn, were sampled in November 1960. Nematodes were few, and no unusual species was detected.

The permanent fallow plots on Fosters and Highfield were sampled at intervals to observe how fallowing affected the nematode fauna. Unfortunately these two sites can only be regarded as partial fallows because weeds were inadequately suppressed in 1960. Nematodes on these sites, as on Barnfield, decreased in spring as in comparable cropped fields, but the numbers in Fosters and Barnfield

did not increase later in the year. On Highfield, however, there was steady increase over the year, because saprozoic nematodes increased; presumably they found the matt of decaying turf a rich source of micro-organisms.

Grass plots on the Woburn Irrigation Experiment were sampled in June, August and October, and a few plots from the barley and bean strips were sampled in October, to study the effects of additional moisture on the nematode population. The irrigated grass in June contained more than twice as many nematodes as the non-irrigated. In August and October this difference was not evident, probably because the excessive rain eliminated most of the moisture differences. The outstanding features of the August and October samplings were that the non-irrigated grass contained more *Pratylenchus* than the irrigated and that there were consistently high differences in numbers of *Pratylenchus* between adjacent blocks. This suggests that there may be big site differences in numbers of nematodes even in land with no recent cultural and manurial differences. As with the Rothamsted classical fields, fertiliser differences seemed to have little effect on nematodes.

Several sites at Rothamsted and elsewhere were sampled at different depths as a preliminary to a larger programme in 1961, when variations in nematode depth distribution with soil type, vegetation, season, etc., will be studied. Nematodes were numerous throughout the top 9–12 inches, and became fewer down to 3–3½ feet, the maximum sampling depth. Different categories of nematodes (root parasites, fungal feeders, saprozoic nematodes), were distributed in different patterns.

At five experimental sites in forest nurseries—Ringwood, Hants; Wareham, Dorset, and three at Oxford—the nematode fauna of plots treated with soil sterilants and sown with Sitka spruce is being studied. *Hoplolaimus uniformis* occurs at Ringwood and can cripple Sitka spruce seedlings, but nematodes seem not to be the primary cause of the poor seedling growth in these nurseries, although there may be an association between nematodes and another pathogen. This confirms work of J. B. Goodey some years ago. In experiments at Kennington, Oxford, and Wareham, Dorset, run by the Chemistry Department the naturally low pH of the soil is varied by additions of sulphur or calcium carbonate to give a range from pH 3 to 7. *Hoplolaimus* spp. and *Trichodorus* spp. were not found at Wareham, but were found at Kennington in the soils with pH artificially raised. *Aphelenchus avenae* occurs at both centres, and is most abundant at the artificially high pHs. In some way, directly or indirectly, pH affects distribution: the coniferous host plants are the same at both sites and over the whole pH range. Another spear-bearing nematode, probably belonging to a new genus of Tylenchida, was found at Kennington in soil where the pH had been artificially lowered. (Winslow.)

Nematicides

Nematicides applied before planting potatoes were tested on Long Mead, Woburn, against potato-root eelworm. Root invasion was used to measure their effect in addition to the usual estimates of

the viable encysted egg population before and after treatment. Yields were doubled by " Vapam " at 1 pint/50 sq. ft., the recommended dose, and there was some increase at considerably lower dosages. Increase in yield was related to the decrease in larval invasion. " Tridipam " and DD had little or no effect. " Nemagon ", orthonitro-chlorobenzene and some other compounds were phytotoxic. (Peachey.)

Some experiments were made with nematicidal dips and with substances mixed with potting soil. Tomato plants dipped in a solution of SD4965 and later planted in root-knot infested soil did not remain free from nematodes. In pot tests " Mylone ", " Nemagon " and SD4014 considerably decreased root-knot infestation of tomatoes. Six chemical dips for the control of chrysanthemum eelworm in chrysanthemum stools were compared with untreated stools, and stools subjected to the standard hot-water treatment. The Parathion dip and hot-water treatment gave the best control. An iodine dip was also effective but too phytotoxic. (Peachey and Hesling.)

Attempts were made to find a means of disinfecting banana " seeds " suitable for adoption in the quarantine service provided by the Royal Botanic Gardens, Kew, for planting stock in transit between the Commonwealth and colonial territories. Iodine, *p*-chlorophenol, a cationic detergent and Parathion were used as chemical dips for " seeds " peeled free from discoloured tissue. These were also compared with " seeds " peeled but not dipped. None of the treatments stunted the subsequent growth of the banana plants; indeed, early growth was improved. Nematode assessment seven months after treatment showed that Parathion considerably, and iodine and the cationic detergent to a lesser extent, decreased infestation by *Radopholus similis*. In another experiment, growing plants were repotted complete with their existing roots into soil mixed with " Nemagon " soil fumigant or SD4014 experimental fumigant, and compared with untreated plants. " Nemagon " gave the best root systems and almost 100% freedom from *Helicotylenchus* spp., *Meloidogyne* spp. and *R. similis*. SD4014 was less effective. A programme of " seed " and soil treatment has now been adopted for quarantine purposes. (Peachey and Hooper.)

At the Royal Horticultural Society's Gardens, Wisley, *Pratylenchus penetrans* was still very rare in carrot plots a year after they were treated with " Vapam " or methyl bromide. Plots treated with ethylene dibromide also had populations well below the original level, whereas populations of the untreated plots had trebled. Although other Tylenchida were less effectively controlled, their numbers showed similar trends, but populations remained below the original level only on the " Vapam " plots. Saprozoic nematodes, after being first brought to low levels by " Vapam ", increased to high levels the following spring and declined to the same levels as in the untreated plots by autumn. Yields from the methyl bromide plots in the second year were again higher than those from other plots, but the differences were less. All treated plots yielded better than the untreated, which yielded less than in the first year.

In another experiment with carrots, " Vapam " at full and half

rates, " Mylone " and a very small dose of a methyl bromide–chloropicrin mixture all almost completely controlled soil nematodes, and DD decreased populations by 90%. The methyl bromide-chloropicrin plots yielded significantly better than all other plots and produced carrots judged to have the best quality. The yield effects in this experiment appeared to be related to " soil amendment " following partial sterilisation rather than to control of plant parasitic nematodes. (Peachey and Winslow.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

M. J. Way, a valued member of the department for seventeen years, left to become Reader in Applied Entomology at the Imperial College of Science and Technology. F. T. Phillips was appointed to replace J. Ward for work on problems of interest to the Colonial Pesticides Research Committee. The Society for Analytical Chemistry has awarded a fellowship to Dr. J. H. Stevenson to work in the department on techniques of microbioassay of residues of insecticides, particularly in plant material. C. Potter, accompanied by B. M. Church (Statistics Department), went to Kenya to investigate methods of sampling pyrethrum flowers. P. E. Burt, C. Potter, M. J. Way and R. Bardner attended the XIth International Congress of Entomology in Vienna, after which M. J. Way visited European laboratories working on insecticides.

By invitation, M. Elliott lectured in Paris on the " Molecular Distillation of the Pyrethrins " to the Comité Français pour l'Etude des Applications des Pyréthrines.

Insecticides

The action of organophosphorus insecticides

Inhibition of cholinesterase from Blatella germanica (*L.*). A preparation of cholinesterase from *B. germanica* was strongly inhibited by " Para-oxon " (*OO*, diethyl-*O*-*p*-nitrophenyl phosphate), physostigmine and " Sevin " (1-naphthyl-*N*-methyl carbamate). The degree of inhibition does not depend on the concentration of the substrate. Both carbamates (physostigmine and " Sevin ") inhibited in the presence of substrate, but higher concentrations were needed than when carbamate and enzyme were briefly incubated before the substrate was added. The inhibition does not appear to be progressive, either in the presence or absence of substrate. The results cannot readily be explained, but the presence in the cholinesterase preparation of an enzyme decomposing carbamates would provide an explanation.

Tests made with " Para-oxon " and physostigmine confirm that phenyl acetate, phenyl propionate and triacetin are all hydrolysed by cholinesterase and not by another esterase. (Lord.)

The mode of action of organophosphorus insecticides on houseflies (Musca domestica *L*). Previous histochemical work showed that treatment with diazinon (*OO*-diethyl *O*-(2-isopropyl-6-methyl-4-pyrimidyl) phosphorothioate) inhibited cholinesterase locally in the thoracic ganglion of *M. domestica* while the brain was less affected. Improved techniques have now shown that, after minimum lethal doses, there is an inhibition in the brain which is usually confined

to the suboesophageal and other motor centres. Inhibition is usually greater in affected than in unaffected flies.

The selective early inhibition of the cholinesterase of the suboesophageal ganglion and the thoracic ganglion, which together control locomotor activity, may account for the poison symptoms of hyperactivity followed by paralysis and twitching of the limbs.

Examining flies at different times after applying the poison showed that there was often considerable inhibition in samples taken immediately after application, whereas symptoms of poisoning did not occur until at least 10–15 minutes afterwards. This examination also provided evidence that the enzyme was being reactivated *in vivo*. Examination of moribund and dead insects showed that in some individuals there was considerable cholinesterase activity in the ganglia, in others there was very little, indicating that there is not a strict correlation between toxicity and degree of inhibition of cholinesterase at these sites. (Molloy.)

Some experiments were done to find whether the apparent reversibility of inhibition of cholinesterase by diazinon *in vivo* also occurred *in vitro*. The oxygen analogue ("oxydiazinon") of diazinon (diethyl 2-isopropyl-4-methyl-6-pyrimidyl phosphonate) was used because this is the likely inhibitor produced from diazinon *in vivo*, but no indication of reversibility was found. With 5×10^{-7} *M*-"oxydiazinon" inhibition increased progressively with time, even in the presence of substrate, and when cholinesterase from fly heads was incubated for 30 minutes with 10^{-7} *M*-"oxydiazinon" it was completely inhibited. (Lord and Molloy.)

Resistance to organophosphorus compounds in houseflies. Histochemical examination of resistant and susceptible strains of *M. domestica* using pure diazinon confirmed that cholinesterase of the thoracic ganglion was considerably inhibited in the susceptible flies but not in the resistant flies 40 minutes after applying a discriminative dose, i.e., a dose that killed the susceptible but not the resistant. With a higher dose both strains showed inhibition. With a dose giving approximately 100% kill, the enzyme was reactivated *in vivo* in both strains 24 hours after application. In the susceptible flies a larger dose inhibited irreversibly. (Molloy.)

Van Asperen and Oppenoorth (*Ent. exp. & appl.* **2** (1959), 48) reported that their strains of resistant flies showed a lower aliesterase activity than their susceptible flies. The rate ethyl butyrate was hydrolysed by extracts of our resistant strains was between $\frac{2}{3}$ and $\frac{3}{4}$ that of our susceptible strains, whereas the ratios obtained by the Dutch workers were between $\frac{1}{4}$ and $\frac{1}{5}$. (Lord.)

To examine the mechanism of inheritance of resistance and to obtain homogeneous material for biochemical studies work was continued on the breeding of housefly strains highly resistant to organophosphorus compounds. The stock strains of *M. domestica* (Sacca selected and unselected, Keiding 203a selected ≡203aA and unselected, the susceptible Dutch strain NH and a strain resulting from the cross Sacca × 203a) all maintained their resistance levels during the year. In an attempt to decide whether diazinon resistance in the Keiding strain is polygenic or due to a single intermediate gene, the distribution of resistance in the population of Keiding 203aA and the susceptible NH strain and crosses and back crosses of these

two strains was determined by a repeated dose technique. The NH strain was fairly homogeneous, but individuals from the 203aA strain differed widely in their resistance, the more susceptible individuals being as susceptible as those from the NH strain. The results from the crossing experiments showed neither the continuous variation characteristic of polygenic inheritance nor clear-cut segregation characteristic of a monogenic factor.

Selection was then started to obtain more homogeneous material from the resistant 203aA strain, both for use in biochemical work and to repeat the experiment on the mechanism of inheritance. Flies were taken from the mass culture of 203aA and given a dose producing about 80% kill. Thirty-five single-pair matings were set up from the survivors. Samples of the offspring of each pair that produced enough offspring were tested for resistance to diazinon. The sibs of four of these groups of offspring which showed most homogeneity for resistance were made up into single pairs, seven or eight from each group. The offspring of these were tested, and those showing too much heterogeneity were discarded; sibs of the remainder were kept for breeding. This was repeated each generation. Now, after eleven generations, there are seven strains of flies derived from the Keiding 203aA, all showing high resistance and a much greater degree of homogeneity. It is proposed to do similar selective breeding of the susceptible NH strain to obtain a homogeneous more susceptible strain and then repeat the experiments on the mechanism of inheritance of diazinon resistance using these " purified " strains. In the meantime the selected resistant strains can be used for biochemical work. (Kruggel and Piall.)

Esterases in eggs of Pieris brassicae *L.* The object of the work is to detect as many of the esterases as possible in the eggs of *P. brassicae*, to isolate them and study their properties, particularly their inhibition by organophosphorus compounds.

Esterase activity was measured using as substrates the phenyl and triglyceryl esters of acetic, *n*-propionic, *n*-butyric and *n*-caproic acids and acetyl choline chloride, acetyl β-methyl choline chloride, propionyl choline perchlorate, butyryl choline perchlorate and benzoyl choline chloride.

Crude breis of 0-10-hour-old eggs hydrolysed the phenyl and triglyceryl esters but not the choline esters. Crude breis of 5-day-old eggs hydrolysed all the substrates.

Crude breis were placed on polyurethane sponge and subjected to electrophoresis at pH 7·4, $\mu = 0{\cdot}05$. The sponge was divided into 30 sections. Using both 0-10-hour- and 5-day-old eggs, the procedure concentrated the protein and nucleic acid, as well as the esterase activity, into three peaks, but all the enzymes moved as a group and there was no separation of enzymes. Differences in movement producing the three peaks could be caused by absorption on different " inert " materials or by the presence of isozymes. (Solly.)

Ovicidal action of organophosphorus compounds. When organophosphorus compounds are applied in doses just sufficient to kill, the embryo develops fully before death occurs; with heavier doses embryonic development is incomplete. The toxic mechanism that

kills but allows full embryonic development may differ from that where death occurs earlier. The temperature coefficient of toxicity of TEPP to eggs of *Pieris brassicae* was studied, first at lethal doses permitting full development, and secondly, at dosages that prevented development. Difference in temperature (15° and 25°) had little effect on the concentrations required to prevent hatching with full development, but at higher temperatures more TEPP is required to prevent development than at lower temperatures. The toxicity of " Para-oxon " depends less on temperature. The difference in the effect of temperature on the toxicity of TEPP at the different dose levels supports the hypotheses that more than one toxic mechanism may be involved. (Lord and Molloy.)

Further evidence was obtained on the significance of inhibition of esterase systems as a cause of death of the egg of *Pieris brassicae* by TEPP and " Para-oxon " poisoning. New-laid eggs, treated with a dose of TEPP just sufficient to prevent hatch, were kept at 15° and examined for esterase activity after 7–8 days, i.e., when they were due to hatch. Hydrolysis of acetyl choline or phenyl acetate was only slightly inhibited. Tests on homogenates of mixtures of treated and untreated eggs indicated that no free poison remained at the time of examination.

When the experiments were repeated with " Para-oxon " enzyme activity was decreased more, but the tests on homogenates of mixtures of treated and untreated eggs indicated that with this more stable chemical there were contaminating residues which caused inhibition when the eggs were ground up. The technique of using excess substrate was tried to overcome the difficulty of contamination, but it failed. The results with TEPP provide further evidence that, if death is caused by inhibition of either cholinesterase or aliesterase, the inhibition is local and not general. (Lord, Solly and Potter.)

Electrophysiological techniques

Several electrophysiological techniques were investigated to see whether they can be used to obtain information on the mode of action of pyrethrins. It is desired to experiment with separate nerve units of an insect whose response to pyrethrins has already been widely studied. Potentials have been recorded from the stimulated labellar hairs of *Musca domestica*, a preparation which has the desired properties. (Burt.)

Pick-up and penetration of dieldrin from residual films

The persistent chlorinated hydrocarbon insecticides are often used to control insect pests by residual films of poison which kill insects coming into contact with them. Little is known of the mechanics of poisoning in this way, so the present work is designed to study the pick-up, distribution and penetration of the poison, and the relationship between the amount picked up and penetrating and the toxicity to the insect.

Adult *Tenebrio molitor* L. were placed on films of dieldrin labelled with radioactive ^{36}Cl, made by evaporating the solvent from 4 ml. of aqueous suspension of dieldrin in 100-ml. wide-necked conical flasks. After a given exposure time, the insects were re-

moved to clean containers and were subsequently analysed, by scintillation counting, for radioactive dieldrin outside and inside the body. The amount of poison left by the insects on the container was also estimated.

Two experiments were done on the relationship between the amount picked up and penetrating and the toxicity to the insect. In the first the insects were exposed for 2 hours to a dose of 500 γ per 33·2 sq. cm. and were kept during exposure and afterwards at 25°. After 30 hours all the insects were either moribund or dead. The mean pick-up was 5·5 γ per individual, the moribund insects averaging rather less (4·4 γ) than the dead insects (6·9 γ). There was a mean of 0·5 γ outside and 3·9 γ inside the moribund insects and 1·1 γ outside and 5·8 γ inside the dead insects.

In the second experiment, a shorter exposure time of 30 minutes was used, the conditions being otherwise the same. Because of the shorter exposure time, less poison was picked up and the insects took longer to die; a mortality of 22% was recorded after 2 days and 84% after 4 days. The mean pick-up per individual of the insects dead after 2 days was 2·7 γ (0·2 γ outside and 2·5 γ inside). A random sample of the insects alive on the 2nd day showed a mean individual pick-up of 2·6 γ (0·2 γ outside and 2·4 γ inside). An examination of the individuals dead after 4 days showed a mean individual pick-up of 1·7 γ with 0·1 γ on the outside and 1·6 γ on the inside. The insects still alive after 4 days had picked up a mean of 1·1 γ per individual (0·1 γ outside and 1·0 γ inside). The results give some information on the actual dose of dieldrin picked up from the film that will kill in a given time, and indicate that the rate at which the insects die is correlated with the amount they pick up from the film.

A third experiment gave some information on the initial rate of penetration into the insect and the amount of poison left by the insects on the container. Nine batches of 15 insects were exposed for 30 minutes to a deposit of 100 γ per 33·2 sq. cm. at 25°, removed to clean containers and kept at 25° until assessing.

TABLE 1

Penetration of radioactive dieldrin into adult Tenebrio molitor *L.*

Time after placing on film (min.)	No. of insects	Dieldrin lost to container (γ/individual)	Dieldrin on surface of insect (γ/individual)	Dieldrin penetrated inside insect (γ/individual)	Total dieldrin on and in insects (γ/individual)
30	45	0	0·30	0·06	0·36
90	45	0·03	0·20	0·11	0·31
150	45	0·04	0·12	0·24	0·36

Table 1 shows that $\frac{1}{6}$ of the dose picked up had penetrated at the time the insects were removed from the film, $\frac{1}{3}$ had penetrated after $1\frac{1}{2}$ hours and $\frac{2}{3}$ after $2\frac{1}{2}$ hours. Approximately $\frac{1}{10}$ of the total dose was lost to the container.

The $^{36}Cl^-$ dieldrin was not active enough to enable individual insects to be examined. More active ^{14}C labelled dieldrin has now been obtained through the courtesy of Shell Chemicals, so that this

work may be extended and individual insects examined for the pick-up, distribution and penetration of the poison. (Rey.)

Pyrethrins and related compounds

Characterisation of cinerins I and II as 2 : 4-dinitrophenylhydrazones. In addition to the pyrethrins I and II, the cinerins have now been characterised as 2 : 4-dinitrophenylhydrazones. Identical derivatives were formed from cinerins obtained by displacement chromatography of pyrethrum extract and by reconstitution from the alcoholic and acid components. This is further evidence that structure does not change during the reconstitution procedure. (Elliott and Thain.)

Infra-red spectra of the components of pyrethrum extract. The infra-red spectra of pyrethrins I and II, of cinerins I and II, of the alcohols and acids constituting these esters and of other constituents of pyrethrum extract, were recorded to assist their identification. (Elliott.)

The enols of pyrethrolone. The structures of the enols of pyrethrolone, compounds formed when pyrethrolone is boiled with methanolic sodium methoxide, were determined. The lower boiling enol is a cyclopentenedione in which the double bond nearer the ring in the diene side chain has been saturated. The higher-boiling enol is a cyclopentane-1 : 3-dione. Both types of compounds are of considerable chemical interest. (Elliott.)

Synthesis of cyclopentenediones. A synthesis of cyclopentenediones by oxidation of cyclopentenolones with manganese dioxide in chloroform has been developed. Many cyclopentenolones are available by synthesis, so this route can be used to make a variety of 2 : 3-disubstituted cyclopentenediones. (Elliott and Jeffs.)

Toxicity to houseflies (Musca domestica *L.*) *of the four active constituents of pyrethrum extract.* Earlier work on the insecticidal activity of the four active constituents of pyrethrum extract used alone (*Rep. Rothamst. exp. Sta.* for 1959, pp. 121–122) was followed by a study of their insecticidal activity when synergised, of their knockdown activity and their full toxicity curves, including knockdown recovery and death. The synergistic factors of the four constituents and their order of relative insecticidal activity were determined over the ratios 0·1 : 1, 0·5 : 1, 4 : 1, 8 : 1 and 20 : 1 synergist : active constituent, using piperonyl butoxide as synergist, acetone as solvent, a measured drop technique and 5-6-day-old flies. Both the synergistic factor [antilog of (log LD50 pure constituent — log LD50 synergised constituent)] and the relative insecticidal activities of the synergised constituents [antilog of (log LD50 of synergised pyrethrum extract — log LD50 of synergised active constituent)] vary with the ratio of synergist to active constituent. At the ratio of 8 : 1 the synergistic factors of the extract and its four active constituents were: pyrethrum extract, 12·0; pyrethrin I, 15·0; pyrethrin II, 6·0; cinerin I, 26·0; cinerin II, 14·0. The relative insecticidal activities of the synergised materials at this ratio were: pyrethrum extract, 1·0 (1·0); pyrethrin I, 1·3 (1·0); pyrethrin II, 0·9 (1·4); cinerin I, 1·3 (0·5); cinerin II, 0·6 (0·6). The figures in brackets show the relative toxicities of the four constituents without synergist.

These results show that the relative insecticidal activity of the constituents alone differs from their relative insecticidal activity in the presence of synergist, because the synergistic factors for the four constituents differ greatly.

Studies on the toxicity curves of pyrethrum and its constituents show that, at a fixed concentration, the progress of the responses to poison can usually be divided into: (1) a very short latent period,

TABLE 2

Knockdown of houseflies (M. domestica *L.*) *by the four active constituents of pyrethrum extract*

Substance	KD50 (% w/v)	KD end point (min. after treatment)	Relative toxicity
Pyrethrum extract ...	0·043	Approx. 13	1·0
Pyrethrin I	0·055	,, 20	0·78
Pyrethrin II	0·021	,, 10	2·05
Cinerin I	0·072	,, 20	0·60
Cinerin II	0·058	,, 10	0·75

when only a few insects are paralysed; (2) the knockdown period, when the number paralysed rapidly reaches a maximum and remains steady during (3) the period of maximum effect, which is followed by (4) recovery of some insects and death of others. Some experiments were done to determine knockdown effects and subsequent recovery or death of flies treated with pyrethrum extract and its active constituents, both alone and synergised. Using the suction technique (*Rep. Rothamst. exp. Sta.* for 1959, pp. 123–124) and applying the materials in *n*-dodecane to 5-6-day-old flies with a treatment and after treatment temperature of 20°, the knockdown

TABLE 3

Concentrations (% *w/v*) *of pyrethrum extract and its four constituents affecting 50% of the insects, 15 and 45 minutes, 2 and 24 hrs. after treatment*

	Concentrations (% w/v) affecting 50% of the insects at specified times							
	15 min.		45 min.		2 hr.		24 hr.	
Substance	U *	S †	U	S	U	S	U	S
Pyrethrum extract ...	0·040	0·016	0·065	0·012	0·080	0·013	—	0·028
Pyrethrin I	0·052	0·012	0·065	0·011	0·070	0·0098	—	0·019
Cinerin I ...	0·082	0·022	0·096	0·016	0·120	0·013	—	0·034
Pyrethrum extract ...	0·050	0·013	0·068	0·0094	0·086	0·0090	—	0·027
Pyrethrin II	0·022	0·0098	0·034	0·0094	0·043	0·0090	—	0·027
Cinerin II ...	0·066	0·018	0·098	0·016	0·014	0·015	—	0·040

* U = unsynergised.
† S = pyrethroid with piperonyl butoxide (1 : 10).

activity of each of the four constituents was compared with that of the extract. Knockdown reached a peak (KD end point) after an interval of time, the length of which depends on the chemical and its concentration. The following table shows the KD50 (concentration to give 50% knockdown at the KD end point) and the KD end point for each KD50. Pyrethrin II and cinerin II have a higher initial

knockdown activity and a faster recovery than pyrethrin I and cinerin I. Adding piperonyl butoxide to pyrethrum extract or its active constituents prolongs the period during which knockdown occurs. At the end of the first 15 minutes the increase in the toxicity of synergised pyrethrum and its constituents is already considerable. Recovery (which begins 2 hours after treatment) is much slowed down and fewer flies recover. In general, the effect of piperonyl butoxide is small initially; it increases with the passage of time. Table 3 shows the extent to which piperonyl butoxide increases the toxicity of pyrethrum or its constituents and blocks recovery. (Sawicki.)

Analytical procedures

The department has taken part in collaborative work on the examination of analytical methods for:

1. Pyrethrum. Collaboration organised by the Joint Panel on the analysis of pyrethrum of the Pharmaceutical Society and Society of Analytical Chemistry. (Elliott and Jeffs.)
2. BHC. Collaboration organised by the Joint BHC/DDT panel of the Scientific Sub-Committee on Poisonous Substances used in Agriculture and Food Storage. (Jeffs.)
3. Demeton-methyl. Collaboration organised by the demeton-methyl residues panel of the Scientific Sub-Committee on Poisonous Substances used in Agriculture and Food Storage. (Lord and Solly.)

Insect rearing

The following insects were reared in the department during the year:

Plant feeding

Hemiptera	*Acyrthosiphon pisum* Harris
	Aphis fabae Scop.
	Brevicoryne brassicae L.
	Megoura viciae Buckt.
	Myzus persicae Sulz.
	Rhopalosiphum padi L.
Lepidoptera	*Diataraxia oleracea* L.
	Pieris brassicae L.
Coleoptera	*Phaedon cochleariae* F.

Stored product, domestic and medical

Orthoptera	*Acheta domesticus* L.
	Blaberus discoidalis L.
	Blatella germanica L.
	Blatta orientalis L.
	Periplaneta americana L.
	Ryparobia maderae Fab.
Lepidoptera	*Anagasta kühniella* Zell.

Coleoptera	*Oryzaephilus mercator* Fauv.	
	Tenebrio molitor L.	
	Tribolium castaneum Herbst	
	Tribolium confusum J. du V.	
	Trogoderma granarium Everts	
Diptera	*Aëdes aegypti* L.	
	Drosophila melanogaster Meig	3 strains
	Musca domestica L.	4 strains

In addition, guppies (*Lebistes reticulatus*) were reared for microbioassay studies.

Bioassay techniques

Because of the sensitivity of larvae of *Aëdes aegypti* L. to contaminating materials other than insecticides, a microbioassay technique with *Drosophila melanogaster* Meig as test insect was used this year for the preliminary examination of bees suspected of being killed by insecticides. A purified extract of the bees was used to produce a film in $1\frac{1}{4} \times 3$-inch glass vials by putting the extract in them and evaporating it while the vials were kept horizontal and continuously rotated. Adult *D. melanogaster* were exposed to the film for 24 hours at 25° and between 60 and 70% R.H. Mortality was then assessed. The flies had access to 10% sucrose solution during exposure.

A " direct assay " method using adult *D. melanogaster* was also developed to determine residues of " Rogor ", the systemic insecticide containing dimethoate (*OO*-dimethyl *S*-(*N*-methylcarbamoylmethyl)phosphorodithioate) in potatoes. This was in connection with work on the use of " Rogor " to check the spread of viruses. The tubers were washed, cut into pieces suitable for mincing and then deep frozen below −10°. The deep-frozen material was minced and homogenised and 25-g. aliquots of the pulp placed in 7-cm. crystallising dishes. Flies were introduced into the test dishes, which were then covered with cellophane and kept at 25° and the mortality assessed at intervals to construct a time–mortality curve. The mortality from test tubers was compared with that obtained in a series where different concentrations of dimethoate were added to the pulp of untreated tubers. This technique detected insecticidal activity in the tubers from the lowered application of " Rogor ", equal to 0·047 p.p.m. dimethoate. This was not the limit of its sensitivity. (Needham.)

The occurrence of bee poisoning in the field. Thirty-three samples of bees suspected of being poisoned in the field were received from Mr. P. S. Milne, the chief bee advisory officer of the National Agricultural Advisory Service. Fifteen were judged to have been poisoned either by organophosphorus or carbamate insecticides, because they gave negative bioassay tests but a positive result by the residual choline esterase technique (*Rep. Rothamst. exp. Sta.* for 1959, p. 124). Two samples thought to contain organophosphorus insecticides gave inconclusive results, but the bees were in an advanced state of decomposition when received.

Six samples contained chlorinated hydrocarbon insecticides,

two dieldrin, one BHC and one DDT. A further sample gave a positive bioassay, but the chemical could not be identified.

Insecticides could not be detected in ten of the samples. One of these, sent as dead, arrived alive and apparently healthy. (Needham and Solly.)

Occurrence of dieldrin in bees. Extracts from some bees, apparently unaffected by poison, proved toxic when used as controls in bioassay procedures. Tests indicated that dieldrin or aldrin was the contaminating material. Through the co-operation of Advisory Officers, nine samples of apparently normal bees were obtained from different localities in England and Wales, and four of these gave a positive bioassay result. Analysis showed that the toxic agent in all four was aldrin or dieldrin, in amount estimated by bioassay to be about 0·04 μg./bee.

Five of the samples examined by us, two of which had given negative results by bioassay, were analysed by gas/liquid chromatography by Mr. Reynolds of the Woodstock Agricultural Research Centre, Sittingbourne, Kent. This technique showed all five samples to contain dieldrin; three had 0·03 μg./bee and two had 0·02 μg./bee. These results suggest that it is common for bees to contain sublethal doses of dieldrin. (Needham and Solly.)

Control of virus spread

Spray timing experiment. The results of the experiment done in 1959 are presented in the Report of the Plant Pathology Department (p. 117). (Burt.)

Soil insecticides to control virus spread. Following the encouraging results of the small experiment done in 1958 (*Rep. Rothamst. exp. Sta.* for 1959, pp. 98, 127–128), a larger trial on early potatoes was done at Efford Experimental Horticultural Station in 1960, using the Latin Square design previously used at Rothamsted. Each plot contained plants with leaf roll and virus Y and there were five treatments: control, DDT emulsion at 2 lb./acre active ingredient, sprayed at fortnightly intervals, and " Rogor " applied in the soil at planting at 2, 4 and 5 lb./acre active ingredient (dimethoate). The potato aphid population was fairly small; 397 aphids per 100 leaves on 22 June was the highest number recorded. The dimethoate treatments all completely controlled the aphids and were considerably better than the DDT sprays. Effects on virus spread will not be known until 1961.

The toxicity to adult *Drosophila melanogaster* of sample tubers from the lifted crop was measured (see section on bioassay). The samples showed toxicity to these insects equal to 0·047–0·076 p.p.m. of pure dimethoate, which agreed well with chemical analyses done by the Laboratory of the Government Chemist and by Messrs. Fisons Pest Control Ltd. Even though the crop was lifted late and sampling therefore delayed, these are very small residues. (Burt.)

Effects of insecticides on beneficial insects

A field experiment similar to last year's *Rep.* (*Rothamst. exp. Sta.* for 1959, p. 125) was done to determine the effects of different aphicides on insect predators of the bean aphid *Aphis fabae* Scop. Some

insecticides were applied at less than the recommended rates in an attempt selectively to control the aphid, leaving predators relatively unharmed. Although there were many different predator species on the plots, only Coccinellid and Syrphid larvae were common. Replicated plots were sprayed on 22 June; live and dead predators collected 3 days later from sheets laid between the bean rows before spraying were:

Insecticide	Dose (oz./acre)	Coccinellidae Adults Live	Coccinellidae Adults Dead	Coccinellidae Larvae Live	Coccinellidae Larvae Dead	Syrphid larvae Live	Syrphid larvae Dead
Demeton-methyl ...	2	0	1	4	25	59	22
Demeton	1	0	3	14	39	41	9
Menazon (" PP175 ")	2	1	1	11	17	80	19
Mevinphos (" Phosdrin ")	1	0	7	0	78	59	61
Fluoroacetamide ...	3	1	1	7	3	48	4
Untreated	—	0	0	15	0	59	10

Mevinphos at about $\frac{1}{2}$ of the recommended rate still killed many Coccinellidae and Syrphid larvae. Demeton-methyl and demeton at $\frac{1}{3}$ of the recommended rate still killed some Coccinellid larvae, as did menazon (" PP175 ") at about $\frac{2}{3}$ of the recommended rate. Fluoroacetamide at the recommended rate apparently did least harm.

The best control of aphids was by the demeton-methyl formulation. The mevinphos, menazon and fluoroacetamide preparations also gave what was considered to be good commercial control, but demeton at 1 oz./acre was inadequate.

The numbers of live predators on samples of 100 stems collected from each treatment 6–8 days after spraying were:

	Coccinellid larvae Old	Coccinellid larvae Young	Syrphid larvae
Demeton-methyl	5	9	34
Demeton	36	43	32
Menazon (" PP175 ")	31	34	43
Mevinphos (" Phosdrin ")	3	6	31
Fluoroacetamide	50	29	50
Untreated	96	67	55

The old Coccinellid larvae were probably present as larvae at the time of spraying; young larvae and Syrphid larvae were probably present as eggs. The numbers partly reflect numbers of aphids, but show that many eggs survived in all treatments, though there were remarkably few Coccinellid larvae in plots sprayed with demeton-methyl or mevinphos. This experiment and last year's suggest that fluoroacetamide and menazon may have a useful selective action for aphid control. Demeton-methyl may also act selectively when applied at less than the normally recommended rate. Tests, in which bees were caged on plants before the spray had dried, suggested that demeton-methyl at 2 oz./acre and mevinphos at 1 oz./acre may still kill some bees working the crop at the time of spraying. (Way.)

Effect of plant density on infestation and control of A. fabae *on beans*

Two experiments were done in co-operation with G. D. Heathcote of the Plant Pathology Department, one at Rothamsted and one at Woburn similar to those described in *Rep. Rothamst. exp. Sta.* for 1958, p. 127, and for 1959, p. 125. These completed the series; provisional results are:

Rothamsted

Plants per yd. row ...	8·3	15·0	26·6	34·8	54·4	67·6	32·5 *
Yield, cwt./acre:							
Unsprayed ...	8·8	7·7	9·2	11·1	12·7	16·0	20·4
Sprayed	15·1	16·5	20·5	18·6	19·6	19·2	20·7
Peak aphid nos. per plant on untreated	1748	1885	1424	932	279	43	37

Woburn

Plants per yd. row ...	6·1	13·2	21·3	32·1	50·5	69·2	26·9
Yield, cwt./acre:							
Unsprayed ...	2·2	2·4	2·7	5·9	12·0	17·3	22·2
Sprayed	12·1	19·8	22·7	24·5	24·6	26·8	32·2
Peak aphid nos. per plant on untreated	3241	3569	2656	1407	246	87	33

Row spacing = 22 inches except * = 11 inches.

Big effects of crop density in all experiments show that initial aphid infestation is usually greater in the thinly sown plots, in which populations also increase faster than in the thickly sown plots. (Way and Heathcote.)

Natural control in relation to chemical control

This work is in collaboration with C. J. Banks of the Entomology Department. Experiments on death of *Aphis fabae* eggs during winter were continued. Results were similar to those in 1958–59 except at two sites; one at Rothamsted, where on one bush exceptionally many eggs were eaten by birds; the other at Hackthorne, Lincs., where many eggs appeared to be diseased. Elsewhere predation by birds and losses from diseases were insignificant. In more severe winters than those of 1958–59 and 1959–60 predation by birds may be more important.

To test whether low temperatures are directly harmful, eggs were kept for varying periods in the laboratory at temperatures down to −20°. Overwintering eggs were killed when kept at −20° for 7 days, but were unaffected by −10° for 14 days and by a diurnal change from −10° to +5° for 4 weeks. As temperatures seldom fall to below −10° in this country, cold is unlikely to kill overwintering eggs of *A. fabae*.

The experiment on the effect of intra-specific competition on rate of *Aphis fabae* increase was repeated in cages outdoors and in greater detail than last year. The results confirmed that such competition is likely to be important in relation to both the natural and chemical control of aphids. (Way and Banks.)

Insecticidal seed dressings

Effects of differences in soil type and leaching on the persistence and toxicity of systemic insecticidal seed dressings. Alkaline fen peat,

acid sedge peat and clay were each mixed with sand in varying proportions to give a number of soils with different characteristics. Wheat seeds, treated with a slurry of phorate and siliceous earth, were planted in pots containing these different soils. Half the replicas were watered every day with excess culture solution to produce leaching, and the remainder of the pots were placed in shallow dishes of culture solution to prevent leaching. Persistence of toxicity was measured by confining aphids (*Rhopalosiphum padi*) on the plants.

With no leaching, toxicity persisted longest with the sand and clay and shortest with peat. With leaching, plants grown in sand, clay or peat lost their toxicity rapidly, and toxicity persisted longest in a peat–sand mixture. Neither sand nor clay seem to hold the insecticide, which rapidly leaches away; it is strongly held on the peat, and is therefore not leached, but only when the peat is diluted with sand and the amount of absorbing material per unit volume reduced, does the insecticide become sufficiently free to be taken up by the plant.

Movement of insecticide from seed to soil. Wheat and mustard seed treated with a slurry of phorate and siliceous earth were sown in John Innes Compost and allowed to germinate and were then transplanted. With wheat aphids and mustard beetles as test insects, transplanted seedlings lost their toxicity much more rapidly than undisturbed plants. This was so even when wheat plants were transplanted with the parent seed attached, suggesting that some of the insecticide moves from the seed to the soil where it is taken up by the plant if undisturbed.

Movement of insecticide in the soil. To obtain information on the behaviour in the soil of insoluble particulate seed dressings, such as the chlorinated hydrocarbons BHC and dieldrin, it was assumed that powdered Saturn Yellow, an insoluble fluorescent dye, would behave like these insecticides. Wheat seeds were treated with a slurry of this dye and planted in John Innes compost, and the distribution of the dye in the soil at intervals after sowing was determined by studying soil sections under ultraviolet light. The effect of different drainage systems on the distribution of the dye was studied.

A method to determine the distribution of organophosphorus insecticides in soil sections was developed in collaboration with Lord and Solly. A gelatin-coated glass slide placed in contact with the soil section absorbs the insecticide on the pattern present in the section. An image of this pattern is produced on filter-paper by moistening the paper with a solution of insect esterases, applying it to the gelatin slide and then treating it with indoxyl acetate. In the areas where insecticide is present the esterases are inhibited and no staining is produced with the indoxyl acetate, whereas the rest of the area is stained. This method was used to study the behaviour of phorate on wheat seeds in John Innes compost at a number of time intervals after sowing. Both sets of experiments showed that some of the insecticide passes into the soil from the seed. The experiments with the fluorescent dye indicated that distribution of insoluble insecticide is assisted by percolation of water through the soil and by germination of the seed. (Bardner.)

Seed dressings for wireworm control. In collaboration with F.

Raw, experiments on the use of seed dressings for wireworm control were started. These are described below (p. 157). (Raw, Potter and Bardner.)

Fungicides

Partial soil sterilisation

Effects of treating soil with formalin and chloropicrin, and with a range of seed treatments, on the distribution of fungi and bacteria in forest nursery soils, planted with Sitka (*Picea sitchensis*), were studied with M. A. Ram Reddy (see above, p. 127). Preliminary experiments were also done with D. B. Slope to see whether the incidence of take-all of cereals, caused by *Ophiobolus graminis*, is affected by applying chlordane, heptachlor and aldrin (insecticides known to decrease the incidence of some fungal diseases) to the soil. (Last.)

Control of potato blight

Triphenyltin acetate, which gave promising results in 1959, was compared in the field with copper oxychloride and zinc ethylene bisdithiocarbamate used at rates of 0·75, 2·5 and 1·3 lb. of active material/100 gallons respectively. Blight was severe in the unsprayed controls, which yielded 9·9 tons/acre of healthy tubers. Spraying with zinc, copper and tin compounds delayed the destruction of the foliage (50% stage) by 8, 10 and 18 days and increased yields by 0·4, 1·0 and 3·8 tons/acre respectively. The increases with tin occurred despite its phytotoxicity, which showed by the appearance of necrotic spots. (Last.)

Cereal powdery mildews

Using fungicidal sprays, the effects of *Erysiphe graminis* DC on the development of spring-sown barley were analysed fully. Soon after leaf infections appeared, decreases in the dry weights of roots were detected. Infection later decreased leaf area and numbers of tillers. The decreases in the root system were disproportionately large, causing the ratio (w/w) of roots to living leaf lamina to decrease. Infected plants produced fewer and smaller ears—a decrease which may be associated with a lower Net Assimilation Rate. (Last.)

Saprophytic organisms in the phyllosphere

Surfaces of living leaves, like roots, appear to provide a substrate suitable for the development of a saprophytic microflora. Factors controlling the incidence of two members of the phyllosphere flora, *Sporobolomyces* and *Tilletiopsis*, were investigated. *Sporobolomyces* occurs on a wide range of plant hosts, but rarely on ferns and conifers; *Tilletiopsis* is less widely distributed and is rare on trees. Colonies of both fungi are usually more numerous on lower than on upper leaf surfaces, *Sporobolomyces* are more abundant on diseased leaves whether (*a*) infected by rust fungi or (*b*) infected with *Aphelenchoides ritzemabosi* (a nematode) and *Eriophyses macrorrhyncus* (a gall-forming mite), than on healthy leaves. Applying superphosphate to

winter wheat increased the numbers of *Sporobolomyces* colonies per unit leaf area; potash decreased numbers and nitrogen had no effect. (Last.)

Laboratory techniques of assessing fungicidal activity

Some variants and possible errors in the test-tube dilution and slide-germination methods of assessing fungicidal action were studied and the results prepared for publication. (McIntosh.)

ENTOMOLOGY DEPARTMENT

K. Mellanby

The sudden death on 5 February of H. F. Barnes, who had been a member of the department for thirty-three years, was a profound shock to all. His entomological work formed a substantial part of the research of the department, and his publications, both in quality and quantity, were such that few Entomologists anywhere equalled his contribution to science. The unique Barnes collection of Gall-midges has been transferred to the British Museum (Natural History), where it will be available for study by specialists from all over the world. Unfortunately the eighth and last volume of his monograph on the Gall-midges was not written when he died, but Dr. W. Nijveldt of Instituut voor Plantenziektenkundig Onderzoek, Wageningen, a friend and collaborator of Barnes, has undertaken to complete this work.

C. G. Johnson received special promotion to Senior Principal Scientific Officer in July; this well-merited honour has given his colleagues in the department and elsewhere much pleasure.

C. A. Edwards joined the department in March. D. S. Madge, an Agricultural Research Council Scholar in the department, was appointed to the staff in October. D. B. Long, who for twelve years has been a most active member of the department and who has contributed greatly to our knowledge of wheat-bulb fly ecology and of the effects of environmental factors on insects, left at the end of the year. Joan Riches left on appointment as entomologist to Reckitt & Sons, Hull, and B. M. Gerard went to the West African Cocoa Research Institute in Ghana. Imam El Khidir from Khartoum and K. Tarman from Ljubljana in Jugoslavia joined the department. C. J. Banks continued his period of secondment to the Central Treaty Organisation Nuclear Centre in Persia.

Nine of the scientific staff attended the XI International Entomological Congress in Vienna in August, though only four of these were fortunate enough to receive grants from the Agricultural Research Council. K. Mellanby visited Nigeria, as the guest of the Federal Government, to attend the celebrations on the attainment of Independence on 1 October.

The University of London conferred the degrees of M.Sc. on Joan Riches, and Ph.D. on B. M. Gerard.

Gall-Midges of Economic Importance

The death of H. F. Barnes meant that much of the work on Gall-midges has stopped.

Broadbalk was sampled for wheat blossom midges for the 34th consecutive year. The infestation was small, 0·6% of ears showing attack by *Contarinia tritici* and 3·9% by *Sitodiplosis mosellana*.

Previous experiments showed that a German winter wheat variety, Marquardts brauner Dickkopf, had a low infestation by

wheat-blossom midges, but it was difficult to decide whether this was because it is unattractive or because it flowers late. Earlier sowing caused somewhat earlier flowering, and in 1960 the attack on this variety was higher than in 1959, but even with early sowing only 22% of ears had burst at the time of the *C. tritici* peak. Escape from infestation probably depends on its late-flowering habit.

Hessian fly (*Mayetiola destructor*) were bred during the winter in a heated greenhouse under regulated conditions, in an attempt to get further information on the factors influencing its speed of development. Under what appeared to be optimum conditions of temperature, light and humidity, individual flies in two successive generations completed their development from egg to adult in 29 days, a speed comparable to that found at midsummer. However, other individuals develop more slowly or cease developing for some weeks, and the cause of this is still not understood.

Material of *S. mosellana*, *C. tritici* and *C. pisi* set up in emergence pots by H. F. Barnes in earlier years remained in the insectary. An attempt was made to extract surviving larvae from some pots, but it proved impossible to separate them from the peat. Emergences from selected pots were recorded; one *S. mosellana* emerged after 19 years.

The transfer of the Barnes Collection to the British Museum, and queries from workers in other countries which continue to arrive, caused a good deal of work. Help was received from G. W. Heath, who worked as an Agricultural Research Council Scholar under Barnes in 1952–54, and who was therefore familiar with the Collection and records. (Arnold.)

Work on swede-midge (*Contarinia nasturtii*) ecology, started elsewhere, was continued with the assistance of Heather M. Twigg of the Ministry of Agriculture, Fisheries & Food Plant Pathology Laboratory. This work was also correlated with other observations in several National Agricultural Advisory Service Provinces.

In plot trials two varieties of kale and savoy, and one each of cauliflower, swede and cabbage were regularly sampled for incidence of midge attack. Only Hungry Gap kale and swedes proved to be susceptible. Crops were sown at weekly intervals, and the results of the sampling showed that the earliest sown crops were most heavily attacked. The form of damage, i.e., "many-neck", "crumple-leaf" and swollen base of the petiole, could be related to the stage of growth at which the plant was attacked. Plants often recovered well from attack even when the initial damage was severe. There was evidence that symptoms apparently typical of swede midge may be caused by other pests.

Traps placed on infested soil and over the crops were sampled daily and showed three peaks of emergence at Rothamsted, approximately on 28 July, 17 August and 30 September 1960. (Edwards.)

The Fauna of the Soil

The very wet weather made autumn sampling difficult or impossible in several experiments, for soil that is waterlogged or submerged cannot be treated by normal methods. This means that results for

several experiments are not available, and that extra sampling will be necessary, if it is possible, in the spring of 1961.

Any quantitative study of the soil fauna, and of its biological importance, depends on a proper identification of at least the more important animals. This department now contains members able to identify to species level most insect pests and also the earthworms, slugs, centipedes, millipedes, spiders, Collembola, and a beginning is being made with the mites. There are still gaps in this soil fauna list, the most serious forms omitted being the Enchytraeid worms and the free-living Nematoda, but it is hoped that work on these will begin in 1961.

Long-term bare fallow plots

The bare fallow plots at Rothamsted and Woburn, started in 1959 and described in last year's report, have been efficiently maintained by the farm staff in spite of the weather, though it proved impossible to prevent a substantial amount of growth on the ploughed-up grass in Highfield. By 1961 it should be easier to keep this plot really free from weeds and grass, and significant effects on the fauna and flora should then begin to be seen. (Mellanby.)

The fauna of Barnfield

The end of the classical root-crop experiment on Barnfield in 1959 made it possible to sample for soil fauna, and the collections then made are being identified. This is proving a long process, but the earthworm collection has now been dealt with. Seven species were found, *Allolobophora caliginosa, A. chlorotica, A. terrestris, Lumbricus castaneus, L. terrestris, Eisenia rosea* and *Octolasium cyaneum*. Numerically *A. caliginosa* and *A. chlorotica* were dominant, but there was a greater weight of *L. terrestris* than of any other species. An estimate of the total weight of worms in the plots (Table 1) shows a much greater weight of worms in the plots receiving dung than in the other plots. Where sulphate of ammonia is

TABLE 1

Fresh weight of earthworms in Barnfield plots

(lbs of worms per acre)

	Dung (14 tons p.a.)	Minerals P, K, Na, Mg	No manure
Series AC, nitrate of soda + rape cake	703	172	215
Series N + sulphate of ammonia	947	15	22
Series A + nitrate of soda ...	557	270	91
Series O, no nitrogen	442	5	35

applied without dung the population is similar to that of plots receiving no additional nitrogen (series O). There is no obvious explanation for the greater weight of worms found in the plot which receives sulphate of ammonia and dung than in the other plots which receive dung. (Raw.)

The Collembola of which there were very many, are being identified. (Edwards.)

Earthworm populations in orchards

The experiment done in 1958–59 to measure the amount of leaf litter buried by worms in five grass and two arable orchards near Wisbech, by placing a known number of weighed leaves on the ground beneath wire cages at leaf fall and recording the number and weight of leaves remaining in spring (*Rep. Rothamst. exp. Sta.* for 1959), was repeated in 1959–60 in a modified form to test whether the amount of leaf litter buried depended on the amount supplied. To do this, twice as many leaves were put under five cages in each orchard as under the other five. This experiment confirmed the results of the previous experiment by showing that, in grass orchards, the number and weight of leaves buried was closely correlated with the weight of the population of *L. terrestris* and was somewhat less than in similar arable orchards. In each orchard more leaves were buried in the five cages with twice as many leaves as in the other five.

In an orchard with a long history of heavy spraying with copper fungicides, which had few earthworms and a surface mat of partially decomposed leaf litter with an abnormally high copper content (1,500–2,500 p.p.m. Cu), an experiment was started (with C. Bloomfield of the Pedology Department) to investigate methods for decomposing the mat by cultivation, with and without additional organic manure. Laboratory experiments were started to see whether earthworms can feed on this mat and, if so, whether any of the copper bound to the organic matter is released. (Raw and Lofty.)

Similar experiments are being made to study the feeding habits of some Collembola which are abundant in the mat. (Tarman and Raw.)

Chemical control of wireworms

Although seed dressings containing BHC will protect wheat from wireworm attack, field experiments have shown that they do this without measurably affecting the wireworm population and that, with heavy wireworm infestations, such seed dressings give less protection than combine-drilling insecticide with the seed. The amount of BHC which can be applied safely as a seed dressing is limited because it is phytotoxic, but this is not so with other insecticides such as aldrin and dieldrin. When Claycroft field was ploughed in spring 1960 it was found to have a high wireworm population, so an experiment was started with wheat as test crop to investigate the effectiveness for wireworm control of BHC seed dressings and seed dressings with standard and increased amounts of aldrin and dieldrin, and to investigate the effect of such seed dressings on the survival and behaviour of wireworms. (Raw and Lofty, with Potter and Bardner, Insecticides Department.)

Wireworm biology

Experiments are in progress to study the effect of temperature on the growth and development of wireworms. The results may help to explain the long larval life of wireworms (3–4 years) and their limited geographical distribution. (Raw and Lofty.)

Rehabilitation of marginal grassland

The experiment at Winder in Lancashire, started in 1954 to study the effect of earthworms in the process of improving hill pasture, continued. Counts in November 1959 confirmed that earthworms are becoming re-established in the plots initially treated with lead arsenate and that these plots will need to be retreated. They also showed that the population of the other plots was only one-third of that of the previous year, possibly a result of the very dry summer of 1959. Such a large change in population could easily mask any effect the fertiliser treatments might have on the earthworm population. Although all plots that have received lime and fertiliser are now much better than the untreated plots, no effects which can be related to the soil fauna have yet been demonstrated. (Raw and Lofty.)

Swift moths

Caterpillars of the Garden Swift Moth (*Hepialus lupulinus*) and of the Ghost Swift Moth (*H. humuli*) live in the soil and feed on plant roots. They seem omnivorous, and economic damage to grass and vegetable crops has been reported. Little information about their biology and ecology exists.

The flight period was assessed by light-trap catches at Flamstead. The Garden Swift moth was caught from 17 May to 24 June with a peak catch of 260 individuals on 6 June. The catch was predominantly males except at first. The Ghost Swift moth was caught between 5 and 22 June; more females were caught than males, and the catch was much smaller than of the Garden Swift moth. It appeared to be important to put the trap on the ground because similar traps put on platforms above ground level caught fewer. Moths marked with coloured paint were released at different distances from the trap, but only very few were recovered in the trap.

Female *H. lupulinus* in the laboratory laid from 50 to 200 eggs and *H. humuli* from 200 to 700. Temperature greatly affected the incubation periods of eggs of both species; they were 9–16 days for *H. lupulinus* and 11–18 days for *H. humuli* at 20°. At 5° eggs did not hatch, but remained viable for over 6 months.

Larvae were cultured in jars containing a base of moist plaster of Paris. After the fourth instar, peat moss was added to the jars, as the larvae sometimes burrowed into the plaster of Paris. Cultures were kept at 5°, 10°, 15°, 20° and some were buried in soil outdoors. The development of the larvae depended greatly on the temperature; larvae developed at 20° approximately twice as fast as at 10°, and at 5° they did not develop beyond the first instar in 5 months. Outdoors when food supplies are adequate, both species probably complete their life cycle in one year. Feeding cycles of the larvae showed a typical growth curve, with a non-feeding phase of 4–5 days before moults. (Edwards.)

Symphyla

Many specimens were received from and identified for workers in various parts of the world, particularly Canada, West Africa and Surinam. (Edwards.)

Earthworm biology

Sampling in a grass field (Pastures) at Rothamsted continued until April 1960. This completed a 2-year period, during which areas of 18 × 18 inches were periodically dug out in 3-inch layers to a depth of at least 12 inches, to determine if vertical movements of the worms, particularly *Allolobophora caliginosa* and *A. chlorotica*, are affected by temperature and dryness. In other experiments, plots were kept unnaturally dry (by covering with Dutch lights) or the soil was kept at field capacity by irrigation, to see how these conditions affect earthworm movement, population dynamics and reproduction (determined by the recovery of the egg capsules). It was perhaps unfortunate that there was no severe cold weather in 1958, 1959 and 1960, so the effects of really low temperatures could not be observed.

Laboratory experiments on the effects of temperature and moisture on egg capsules, immature and mature worms were continued, as were observations on the effects of light, temperature and moisture on worm activity in the field. *Lumbricus terrestris* came out of its burrow at any hour, provided the ground was moist, light excluded and the temperature was above 5°. (Gerard, Raw and Mellanby.)

Slug investigations

The detailed life histories of *Arion hortensis* and *Milax budapestensis* are being worked out using the culture methods evolved during last season. The rate the young develop at constant and fluctuating temperatures, and the feeding rate of *M. budapestensis* at constant and fluctuating temperatures, are being studied.

Damage to Majestic and Arran Pilot tubers was assessed in a crop grown at Rothamsted Lodge for the second year. The results provide an interesting comparison between a dry season, 1959, and a wet season, 1960. A new technique capable of giving quantitative results has been devised, based on measuring the size of the holes made by slugs in the potatoes.

Three insect repellents, dimethyl phthalate, dibutyl phthalate and benzyl benzoate, and salicyl aldehyde (both the naturally occurring and the synthetic forms) were tested against slugs. All were repellent and toxic to slugs, and the possibility of using them as seed dressings was explored. Unfortunately all the compounds have some phytotoxicity, but at low concentrations they decreased the hollowing of wheat grain by *Agriolimax reticulatus*.

A preliminary experiment was started to explore the possibility of assessing slug populations more accurately from the results of trapping. Square-yard quadrats were sealed off by driving metal plates into the soil to a depth of 1 foot, and the slugs coming to fresh bran/meta bait in these traps were collected daily. Slugs immobilised under wet sacks placed adjacent to the quadrats were also collected daily. This allows the catches on the bran baits to be related to slug activity and temperature on any particular night, and it is hoped the results will show how many nights' continuous trapping within the quadrats are needed before the slug population, both surface and subterranean, can be estimated. (Stephenson.)

Experiments to find the effects of low temperatures on slugs, and the biological zero, were begun. *A. reticulatus*, a pest of winter wheat in late autumn, is particularly adapted to life at low temperatures. (Mellanby.)

Mite investigations

The feeding behaviour and digestion of Oribatid mites, the correlation between food habits (i.e., microphagous, macrophagous, wood eating) and digestive processes, were studied by histological and histochemical methods. (Tarman.)

Ecological work near Woburn included taking monthly samples from (*a*) lichen in between *Calluna* tussocks in heathland, (*b*) ground moss from an adjacent oak-chestnut woodland; samples of litter and humus from Geescroft Wilderness at Rothamsted were also regularly examined. Temperatures and other data were recorded, and the mites are being extracted from the samples for identification.

Results from laboratory investigations on the physiology and behaviour of the different species of Oribatid mites are being related to the microclimatic conditions of the natural sites of the mites. The water balance of several species was studied, together with the anatomy of the respiratory system and the structure of the cuticle. (Madge.)

Biology of forest soils

Work continued on the changes in weight of the leaf litter under beech and oak. Labelled leaves of beech (in an 18-year-old stand which has achieved closed canopy) and oak (from both an 18-year-old stand and from a 50-year-old natural regenerated oak-dominant woodland) were sampled at 14-day intervals for 12 months. The samples consisted of small disks of leaf lamina punched from the labelled leaves. During the 12 months the dry ash-free weight per unit area of leaf lamina has not varied, and no significant loss in weight was detected at the end of the year. No attempt was made to put the leaves in any particular stratum of the litter layer, and so much of the time they were on the surface. Observations indicated the lamina break down or fragment at the bottom of the litter layer. Experiments were therefore started in which large disks of beech and oak leaves were placed at the bottom, middle and top of the litter layer. Sampling of this experiment should measure the rate and extent of leaf fragmentation. An associated experiment with similar disks will give information on the removal of leaf material by earthworms.

The respiration rates of soil animals were again measured. The apparatus used maintains constant O_2 partial pressure by generating oxygen on demand electrolytically; this output can be recorded daily. In experiments with Isopods oxygen demand was between 0·10 and 0·30 mm^3 O_2/hr./mg. of body weight. The apparatus is not yet sensitive enough for animals as small as the litter-living mites, but it is being improved. With a small core of soil containing Collembola in the respirometer the oxygen demand was between 0·02 and 0·04 mm^3 O_2/hr./ml. of soil. The soil animals in the core survived in the respirometer for several weeks.

Leaf traps in the young oak and beech stands at Rothamsted

showed that in both stands the amount of organic matter falling on to the woodland floor during autumn was about 2,500 lb./acre of dry matter. The percentage total carbon of this material will be estimated as it decomposes. Preliminary observations suggest that the measurement of respiration rate of the soil milieu and its animal population, taken in conjunction with changes in the total carbon content of the litter, may be the most profitable line in elucidating the role of the soil fauna in forest soils. (Heath.)

Insect Dispersal and Migration

Work was mainly devoted to drawing together, into a general system, the diverse aspects of dispersal and migration of insects and to continuing the analysis of the many results on the vertical distribution of various insect species (especially aphids) collected over the past 10 years at Cardington.

Progress towards a general functional system of insect dispersal and migration was helped by the recognition that many classical " migrations " begin at a breeding site by the newly emerged adults often on their first flight or on one relatively soon afterwards. In this respect such migrations resembled the normal initial dispersal process from the breeding site of many insects not generally recognised as migrants. It is true that so-called mass " migrations " in some species are made also by much older adults, already with a flight history, as from hibernation or aestivation sites, but the post-teneral migration flight from the place of birth is nevertheless apparently common to all. This introduces a new perspective to a hitherto diffuse subject, and the possibility appears of making a general functional system of migration and dispersal for a very wide range of insect species. Mass flights (a characteristic of many migrations) can be linked with mass emergence, and with the recently constructed mechanism of post-teneral daily flight rhythms, as in aphids. Migration and dispersal (hitherto seen as distinct processes) are recognised as aspects of the same process, and the spectacular orientation and persistence of some migratory flights can now be seen not, as is customary, as a general feature but as a very special one. Thus both " dispersal " and " migration " are processes for redistributing populations from the original breeding site. The methods by which this is achieved range from spectacular feats of orientation and persistence by strong fliers to drift on the wind by weak ones.

The task now is to systematise the mass of existing information within this perspective and to distinguish general from special problems. (Johnson.)

Ecological Studies on Whiteflies

Work on the cabbage Whitefly (*Aleyrodes brassicae* Walk.) began in April with special attention to flight activity. A 9-inch segregating suction trap, working in a cabbage plot from 15 August to 28 September, showed a daily flight periodicity with a maximum near midday. Little flight occurred at night, probably because of low temperature rather than of darkness, for when temperatures rose above the flight

threshold at night the insects flew. The temperature threshold for take-off was approximately 9°.

Numbers caught per hour and ambient temperature are not always correlated positively, as the catch may rise with a falling temperature, and vice versa. As with aphids, this may reflect changes in population level rather than changes in behaviour; the relation between the moulting into adults and take-off is being studied in the greenhouse to elucidate this point. Emergence is rhythmic, usually occurring maximally between 8·5° and 16·5° with a threshold of 6°. The difference between emergence and take-off thresholds tends to make new adults accumulate while waiting to take-off. Females are usually about 10 times as numerous as males in the trap. Collections from the crop itself show that this is only partly because of an absolute preponderance of females, for the crop contains proportionally more males than are present in the traps. This suggests the flight behaviour of the sexes differs. (Imam El Khidir and Johnson.)

Sampling Limits for Suction Traps

To make the best use of suction traps it is necessary to know how insects are distributed in the air. Like all sampling devices, we want to know within what limits reliability can be placed on any given catch or sample. This is being investigated. It seems that, at any specific instant, the distribution of most insects in the air is approaching random; in other words, most insects in flight are quite independent of each other, and this is true for most of the common orders. However, the chronological changes in distribution are highly interdependent, as might be expected, and this dependence differs between orders. It is expected that tables of limits of accuracy for catches will be published shortly.

In the course of this investigation it was necessary to find a suitable method for transforming catches before statistical analysis. The logarithmic transformation [log $(n + 1)$] is often used, but is not entirely satisfactory. This led to an examination of published work, and a general transformation was found for any degree of aggregation. It is based on the empirical relation: variance is proportional to the mean raised to a positive fractional power (b), where b is a measure of aggregation, i.e., $s^2 = am^b$. This also has considerable biological interest, in the use of b as an Index of Aggregation, making it possible to compare the degree of aggregation in different species, or in the same species in different habitats. The relation also contains another parameter a which is affected by sampling and computing procedure. The several aspects of this problem will be investigated in collaboration with M. J. R. Healy of the Statistics Department. (Taylor.)

Flight Thresholds in *Aphis fabae*

The minimum air temperature at which free horizontal flight occurred was 10°; 50% of test insects flew horizontally at 13°. For upward flight the minimum air temperature was 12°; 50% flew upward at 16°. The higher temperature threshold for upward

flight is probably caused by higher metabolic requirements. There was no evidence that aphids kept previously for 24 hours at 5°, 10° and 15° were acclimatised towards lower flight thresholds than aphids kept at 20°. These results apply only to the first few seconds of flight.

Wing-beating occurs at temperatures below the threshold for successful flight; tethered aphids beat their wings, generally at low stroke amplitude, at 3–7°. In nature such movements may decrease sinking and so aid dispersal. Below 9°, however, wing-beating is maintained for less than 15 minutes. (Cockbain.)

A Fungus Pathogenic to the Bed-bug

Bed-bugs (*Cimex lectularius*) kept at 30° and 90% relative humidity became naturally infected with *Aspergillus flavus*; this is apparently the first record of a fungus attacking *C. lectularius*. When the insects died, yellow hyphae grew through the ventral body surface and through the joints of the appendages. Sometimes the fungus emerged and began to sporulate before the insects died. All insects died within 18 days of the outbreak.

Pathogenicity tests with 2nd instar nymphs and adult bugs from an uncontaminated culture showed that inoculated bugs died sooner than controls. Bugs kept at 30° and 50% relative humidity, and 20° and 90% relative humidity, did not show the fungus externally; at 30° and 90% relative humidity, which is probably near the optimum for fungal growth in the bug, hyphae penetrated to the outside of the cuticle. (Cockbain, with Hastie, Plant Pathology Department.)

Wheat-bulb Fly

Larval studies

A mean population of 298,000 larvae/acre in wheat after fallow on Broakbalk, following the smallest recorded population for that field of 55,000 larvae/acre in 1959, demonstrates the ability of wheat-bulb fly to multiply. The distribution of the population across the field was similar to that observed 5 years previously, with numbers decreasing from the middle of the field to the southern boundary.

The detailed study of the interaction between larva and plant undertaken with the collaboration of Marjory G. Morris of the Statistics Department shows that local plant density is important, both for the success of the developing infestation and for crop recovery. Thus, in wheat sown at low density, a population was only one-twenty-fifth as successful in passing through the larval stages up to pupation as a comparable population in wheat sown at the normal rate, largely from two factors associated with low-density wheat: first, many more larvae died in the plants (although they tillered more freely), and secondly, more larvae died in the transition from shoot to shoot. The results of the new technique used in 1959 suggested that crop recovery depended principally upon compensatory development in undamaged plants. Damage retarded plants up to 4 weeks and, although they subsequently produced more buds

and shoots than undamaged plants, they failed to replace all the damaged shoots and fewer survived to harvest in such plants than in those undamaged.

To continue the study in 1960 a new field technique was developed for observing the progress of the infestation in the experiment on Alternate Wheat and Fallow. This depended on the integration of the results of three sets of independent observations. On seven successive occasions 480 samples, each comprising 1 inch of row, were taken from 16 30-inch sectors of row and examined in the laboratory. Thus larval and plant growth could be related to the spatial distribution of damaged and undamaged plants in the field. In another series of 30-inch sectors the spatial distribution of 500 plants was recorded, when they were individually marked as damaged or undamaged and the progress of the larval infestation and plant growth in the field were observed until pupation. At harvest these labelled plants were removed to the laboratory, where the lengths of the straw and ear, and the number of grains and their weight, were recorded. The possible effect of shoot-age affecting the distribution of larval infestation was also investigated by a " choice " experiment in which 650 tubes each containing a young wheat seedling and a single-shooted older plant were each inoculated with a single larva. The age of the larvae and their subsequent distribution between young and older plants were recorded. The analysis of the results of these and earlier experiments is being continued by Marjory G. Morris. (Long.)

Adult studies

The diurnal rhythm of activity affects both movements within crop and the dispersal of the fly. Much of the behaviour appears to be influenced by changes in light intensity, and activity is maximal at very low intensities. Experiments on the opto-motor responses of the fly in relation to light intensity had to be abandoned because of the wet weather. (Long.)

Population Density Effects

The effect of larval population density on the development of the subsequent generation, indicated previously with *Plusia gamma*, was investigated on a larger scale. From a common stock solitary and crowded cultures were set up as independent lines and bred through four generations. By reversing the culture density in one-half of each line in F_2 and F_4 generations, the effect of the parental experience could be studied by comparing the development of larvae reared under similar conditions of population density. The study was extended in the F_4 generation to include the maturity period, fecundity and lifespan of the adult moth. The results, which await statistical analysis, do not show the clear differences in the number of instars between the two lines observed in 1958.

Experiments on the effect of pairing and adult population density under constant temperature on maturation period, fecundity and lifespan are being completed, and results obtained to date suggest that copulation stimulates egg laying. They also confirm previous findings that nearly twice the number of eggs per female laid by single

pairs are laid when two pairs are kept together and suggest that this happens because of stimulation by another laying female rather than by the presence of another male. (Long.)

Insect Migrations

The records of migrant lepidoptera show that almost all species were rare in 1960. Reports of the Red Admiral (*Vanessa atalanta* L.) in January, February and March indicate the ability of this butterfly to overwinter successfully in the south of England, particularly during a mild winter such as that of 1959–60. A few individuals of other "migrants", especially the Humming-bird Hawk Moth (*Macroglossum stellatarum* L.), may also have survived the winter. That these overwintering insects contribute little to the summer population is indicated by the scarcity of records throughout the rest of the year. In addition to the above insects, all the other regular migrant lepidoptera, except one, were present in only small numbers. The exception was the Convolvulus Hawk Moth (*Herse convolvuli* L.), which was more numerous than usual because of an immigration from the south at the beginning of September.

Among the scarcer immigrants, two species are of particular interest, the Rannoch Looper (*Itame brunneata* Thunb.) and the Great Brocade (*Eurois occulta* L.). Seven specimens of the former were caught in south-east England, six of them on the nights of 25 and 26 June. All the moths were of the pale continental form, as opposed to the dark Scotch form. *E. occulta*, another Northern species, was recorded at the beginning of August in several localities where it is unlikely to have bred; some of these specimens, too, were identified as of the continental form.

During the first week of August movements of Syrphids were reported from several localities in south-east England. Although Syrphids were, in fact, common over much of England, the migrations were noticeable, particularly along the coast from the Isle of Wight to Lincolnshire. The direction of flight varied between localities, but the insects were usually recorded as coming in from the sea. On the few occasions when the species were identified they were principally aphid-eating species. (French.)

Sciomyzid Investigations

Prof. C. O. Berg of Cornell revisited Rothamsted, staying from 17 June to 11 July. During the first week he was accompanied by Mr. Ll. Knutson. The work on *Pherbellia schoenherri* started in 1959 was completed, and the results are being written up. Additional members of the Sciomyzidae were taken in the United Kingdom by Prof. Berg on collecting trips. On these the biology of *Verbekea* sp., *Ditaenia cinerela*, *Pherbina coryleti* and *Sciomyza albocostata* has been in part worked out. Information has also been obtained on the host range of the larvae of these species. (Stephenson.)

Spiders

Field surveys at Rothamsted showed rather few spiders (about 50,000/acre, compared with more than 4,000,000/acre in some habitats). It was felt that work on the economic importance of such populations would be difficult, so the main effort was devoted to laboratory experiments and study of a natural infestation in the glasshouse corridor.

An attempt is being made to determine the amount of food consumed by the spider *Zygiella x-notata*, and the effects of different feeding regimes on its growth and survival. Spiders, individually in glass tubes, are kept at 10°, 15°, 20° and 25° and fed on *Drosophila*. Different groups of spiders receive different numbers of flies, and the actual amount of food taken is estimated by removing the fly corpses and analysing them. (Tallack.)

Frit Fly

Work on the frit fly in the field and in the laboratory continued for the third successive year. On Geescroft an experiment similar to one made in 1959, planned to make possible the forecasting of frit-fly attack, was made in collaboration with Mr. A. H. Strickland and Mr. K. S. George of the Ministry of Agriculture, Fisheries and Food Plant Pathology Laboratory. Two randomised blocks of 2 plots, with 2 replicates, were sown on 17 March, 7 April and 21 April. Fly numbers and fly behaviour were studied throughout the season; the results are being compared with observations in other parts of England.

An analysis of damage to the oat panicle was completed, and the results published (10.25.) (Riches.)

The seasonal population change and diurnal flight pattern of the frit fly (*Oscinella frit* L.) were studied in 2 acres of late-sown Sun II oats in Great Field II, by the use of a disk-dropping suction trap, which was initially buried in the ground, but raised during the growing season to keep its mouth at crop level. Hourly catches show that the flies become active about 3 hours after sunrise and stop flying about sunset, with a peak of flight between 1400 and 1600 hours G.M.T. These times varied little over the whole trapping period from May to September. The flight pattern is being further analysed to see the effects of air temperature, light intensity and wind speed. Over most of the season the catch contained more males than females; but during two short periods considerably more females than males were caught. Adult flies emerged most abundantly from pupae in freshly collected oat spikelets at about 0800 hours G.M.T.

Fewer eggs were laid on panicles exposed either before or after flowering than on panicles exposed during flowering.

The nematode parasite, *Howardula oscinellae*, occurred in 3–4% of the flies examined.

A cage of terylene net, 24 feet square and 6 feet high, was placed over part of the crop, before the panicle generation emerged, to isolate this area in an attempt to measure movement into or out of the crop during this period. The infestation inside the cage was

lower than outside, particularly in panicles which were late in flowering.

Work began to study the overwintering of frit fly larvae in winter oats, sown on 29 July, 10 August and 26 August. All three sowings were infested by adult frit flies emerging from the panicles of the spring-sown crop, and the infestation was particularly large in those sown on 10 August. The infestation in this crop is being followed by dissecting samples at intervals to see the effect on the plant and the mortality of the frit larvae. Up to the end of 1960 no pupae were found, and larval mortality has varied considerably, but not consistently, with time. Tillering has continued and increased in proportion to the number of damaged shoots. (French, Bull and Mellanby.)

Some of the frit fly population studies have contributed to the general problem of insect trapping. The white glass sticky traps (" Ibbotson " traps) and white or yellow water traps clearly attract frit fly and other diptera. This is useful to detect attracted insects when they are scarce, but the results require careful interpretation. When water traps are painted " grass-green " (to a special formula advised and tested for reflection and radiation by Miss D. L. Tilleard of the Paint Research Station, Teddington) the catch is quite different, and is perhaps more nearly a random sample. It is of interest that white water traps sometimes caught many honeybees, to the concern of our colleagues in the Bee Research Department; the green traps in the same situations caught very few.

Green tray water traps were placed at 25 sites spread over Rothamsted farm, and the catches are being compared with those obtained by suction traps. (Calnaido.)

BEE DEPARTMENT

C. G. Butler

L. Bailey was awarded a Kellogg Fellowship, and spent four months visiting Universities and research centres in the U.S.A.

An exhibit on the pollination of fruit trees was shown at the Chelsea Flower Show, the Royal Agricultural Show, the Institute of Biology Annual Conversazione and the National Honey Show.

Behaviour and Physiology

Swarming

Further evidence has been obtained to support the view that a queen, when grooming, distributes the queen substance secreted by her mandibular glands over her body surface, so supplying it to her workers and inhibiting them from queen rearing. In a series of experiments queens of colonies were prevented by collars from touching their mouthparts with any of their limbs. Although the mandibular glands of these queens contained as much queen substance as those of control queens, none was detectable on their bodies after a few days, whereas some was always detected on those without collars. (Butler.) The collars prevented the queens from moving around the combs and laying normally, and to overcome this other experiments were made in which the front legs of the queens of 13 colonies were amputated. The amputation led to the appearance of eggs in queen cells and to the rearing of queens. In August this was followed by the complete process of queen supersedure, in which the old queen survived until the young one was mated and laying. Earlier in the season the old (experimental) queens died naturally or were killed, before or soon after the young ones emerged from their cells and, although two of the colonies swarmed, they did so with young (virgin) queens. Whether removal of a queen's front legs interferes with queen substance distribution, or decreases the amount secreted is not yet known. (Simpson.)

The construction of a very large observation hive (16 British Standard brood combs in 6 tiers of 3) has made it possible to study the behaviour of colonies which swarm even though they are not crowded. Two colonies apparently preparing to swarm were put in this hive, and the queen in each died naturally, or was killed by the bees, before swarming occurred. One of the colonies did not swarm, the other did so with a virgin queen. The first worker bees to show excitement before the swarm emerged were in that part of the hive farthest from the entrance and at least 30 cm. from the queen or the nearest queen cell; thus the excitement was probably not caused by the queen, the queen cells or by bees who had inspected the weather outside. Nor was it caused by the queen departing on a mating flight, as about half the colony had left the hive before the queen reached the entrance tunnel, and she was

driven out by the workers while repeatedly trying to return. The workers did not actually push the queen, but those beside her stopped moving forward whenever she did, so that a mass of bees she could not penetrate, piled up behind her. Later, when mating flights occurred, the queen always ran straight through the entrance tunnel as soon as she found it, and the number of workers leaving the hive did not increase while she was going out. (Simpson.)

Old queens from 11 swarms from uncrowded hives each had only about a quarter as much queen substance as each of six mated laying queens from colonies free from queen rearing; in their content of queen substance they were indistinguishable from seven queens that had been superseded. (Butler.) Attempts are being made, therefore, to find difference in the behaviour of workers of uncrowded colonies in which queens are being reared preparatory to swarming and supersedure respectively. Observations will have to be continued for several years to seek consistent differences in behaviour. So far " piping " of queens, confinement of young adult queens in their cells by the workers, and dorso-ventral abdominal vibration dancing on queens, which are generally associated with swarming, have been seen in three supersedures when the old queen died naturally, or was killed by the workers, before or immediately after the young one emerged from her cell. These behaviour patterns have not been seen in complete supersedures when the old queen survived until the young one, who superseded her, had mated and begun laying. Thus incomplete supersedure may be intermediate between complete supersedure and swarming. (Simpson.)

Queen substance which, at the time of the last report, had been isolated and partly identified [Butler, Callow and Johnston, *Nature*, **184** (1959), p. 1871] has now been identified as 9-oxodec-2-enoic acid [$CH_3 \cdot CO \cdot (CH_2)_5 \cdot CH{:}CH \cdot COOH$] and synthesised [Callow, R. K. and Johnston, Norah C., *Bee World*, 1960, **41**, 152–153]. The synthetic material is as active in inhibiting ovary development in worker bees and queen rearing by them as the natural material isolated from the mandibular glands of queen honeybees. (Butler, Callow and Johnston.) However, the odour of 9-oxodec-2-enoic acid is not attractive to worker bees, whereas another substance that can be extracted from a queen in ethanol attracts workers a short distance away. Presumably, in the darkness of the hive, it helps workers near the queen to find her and so to obtain queen substance by licking her body. Work has begun, in collaboration with Dr. R. K. Callow and Miss N. C. Johnston, to isolate and identify the material responsible for a queen's attractive odour. (Butler.)

Ethanol extracts of *Apis indica* and *A. florea* queens (kindly supplied by Mr. L. A. S. Perera) inhibited queen rearing by *A. mellifera* workers, so queens of these species presumably also produce 9-oxodec-2-enoic acid in their mandibular glands. (Butler.)

Stinging

The factors provoking bees to sting were studied by comparing the number of times balls of cotton-wool, wrapped in muslin, were stung when treated in various ways and jerked over the top of an open hive or at a hive entrance.

Black balls were stung more than white against both black and

white backgrounds, and blue more than yellow against yellow or blue backgrounds. However, white balls were stung more than yellow against a yellow background and yellow balls were stung more than white against a white background, thus showing the effect of contrast.

Balls that had already been stung were more likely to be stung than fresh balls offered simultaneously, but the " sting odour " was effectively masked by " smoking " the balls. Bees stung balls that had been kept in their own hive, and so probably acquired something of their colony's odour, more than balls that had been kept in the hive of another colony. The reason for this is unknown. The scent of mammals and of human sweat provoked stinging, but treating balls with such insect repellents as dimethyl phthalate, citronellol and methyl salicylate decreased it.

Balls with half their surface areas covered with wool were stung more than muslin-covered balls, probably because of their texture. Also, the more rapidly a ball was moved, the greater the number of stings it received.

These results suggest that chances of being stung are decreased by wearing clean, smooth-textured, light-coloured clothing, by avoiding rapid movements and sweating, by using a repellent and by " smoking " any places that are stung to mask the " sting odour ". (Free.)

Queen rearing and introduction

The records of two honey-farmers (Messrs. R. O. B. Manley and A. S. Rowse) were analysed. Some of them show that queen cell cups containing newly grafted larvae were more readily accepted by queenless and broodless colonies than by queenless colonies with brood or by queenright colonies, and more readily accepted and completed by queenless colonies with brood than by queenright colonies. Acceptance was not influenced by the presence of unsealed queen cells in the recipient colonies or by the presence of food with the larvae in the cups.

Success in introducing sealed queen cells, virgin queens and mated laying queens to colonies was greatest when the queen of the recipient colony was either the same physiological age or a little younger. For example, sealed queen cells and virgin queens were more readily accepted by colonies that had been queenless for 3 days, and had probably started to produce queens of their own, than by colonies whose queens had been removed more recently. Again, cells from which queens were due to emerge within 4 days were more successfully introduced to colonies that had been queenless for several days than to colonies that had been queenless for shorter periods, and younger queen cells were more successfully introduced than older ones to recently dequeened colonies.

Mated laying queens were less successfully introduced to colonies from which virgin queens, queen cells, or a laying queen and queen cells had just been removed, than to colonies from which laying queens had just been removed.

The time of year was not correlated with the proportion of queen cell cups containing newly grafted larvae that were accepted and reared. During June and July the proportion of sealed queen

cells and virgin queens accepted was greater than at other times of year, but the proportion of mated laying queens accepted was smaller. The success achieved both in queen rearing and in the introduction of sealed queen cells and adult queens varied greatly from year to year. (Free and Spencer-Booth.)

The feeding of colonies

During two years colonies were fed either with dilute or concentrated sucrose syrup in spring, summer and autumn, and compared, during the week before feeding began, during the week of feeding and during the week after feeding, with unfed control colonies.

The amount of syrup taken increased as the season progressed. In each experiment more of the concentrated than of the dilute syrup was taken and, although the proportion of concentrated to dilute syrup accepted decreased between spring and autumn, the amount taken in spring was so great that the colonies receiving it obtained more water from it than those receiving dilute syrup. The concentration of the syrup made little difference to the proportion of sugar from it that was stored as " honey ".

The experimental colonies had significantly more brood both during and after feeding in 1958 with both syrup concentrations, but feeding had no detectable effect on brood rearing in 1959. The weather was more suitable for foraging in 1959 than in 1958; feeding syrup probably increases brood rearing when the weather is unfavourable for foraging, but has no effect when incoming food from natural sources is plentiful. The feeding of dilute or concentrated syrup probably lessened nectar-gathering when foraging conditions were good, and concentrated syrup may have lessened it more than dilute syrup.

While being fed, colonies collected increased amounts of pollen in both years. Pollen-gatherers are more valuable than nectar-gatherers in pollinating many crops (e.g., field beans, red clover, fruit trees), so the practice of feeding syrup to colonies that are taken to such crops will probably increase the amount of pollen they collect, and hence their efficiency as pollinators. (Free and Spencer-Booth.)

Bees can ingest dry sugar by dissolving it, or reducing it to a paste, with saliva from their labial glands (not with material from their honey-stomachs). The bees of a colony in an observation hive took granulated sugar slowly from a feeder of the Miller type. At first few bees licked the sugar, but later the whole surface became covered with feeding bees. Many bees, however, picked up grains of sugar in their mandibles, carried them to the hive entrance and flew away with them, presumably dropping them eventually. The proportion of sugar lost in this way has not yet been determined, but may be enough to make this method of feeding uneconomical. Icing sugar was not carried out by the bees, but proved unsuitable, as the bees became so heavily dusted with it that they could not go on feeding. (Simpson.)

Effect of cold

Experiments were made to find what factors determine the highest temperatures at which worker honeybees are immobilised by cold (chill coma temperature) and killed by cold (cold death temperature). The chill coma temperature for workers varied between +8° and +11° and was in general lower than that for queens and drones. Workers kept for some time at 20° had lower chill coma temperatures and recovered more rapidly from chill coma than workers that had been kept at 35°. Conditioning to a given temperature was complete after 24 hours.

Bees taken directly from the hive had a lower chill coma temperature in winter than in summer, but after conditioning at a given temperature for 24 hours this difference disappeared, so winter bees seem only temporarily conditioned to lower temperatures and not to have an intrinsically low chill coma temperature. The chill coma temperature of a bee decreased with age, which could partly be explained by the fact that older bees tend to keep away from the brood area (where the temperature is highest) when in the hive and so become conditioned to lower temperatures than younger bees who frequent the brood area. Nevertheless, even after conditioning at 35° for 24 hours old bees still had lower chill coma temperatures than younger ones, although the difference was smaller.

Most workers died after 50 hours in chill coma, and few lived more than 80 hours. More survived at +5° than at 0° or +10°. Cold death occurred between −2° and −6°. Between −3° and −5° the death rate increased as duration of exposure was increased from 30 to 180 minutes. The temperature to which the bees had become conditioned apparently did not affect the cold death temperature.

Apis indica workers entered chill coma at temperatures slightly higher than *Apis mellifera* workers. Groups of both *A. indica* and *A. mellifera* workers responded to low temperatures by eating more food, indicating increased metabolism and heat production. (Free and Spencer-Booth.)

Functions of salivary glands of adults

Invertase is secreted by the hypopharyngeal glands of worker honeybees, but not by their labial or mandibular glands. Queens and drones have no hypopharyngeal glands, and it has now been confirmed that their labial and mandibular glands contain no invertase, so they evidently have no salivary invertase. All honeybees secrete invertase in their mid-guts, and this enzyme is presumably necessary in the saliva of workers to invert sucrose during the ripening of nectar, which does not enter the mid-gut. (Simpson and Riedel.)

The mandibular glands of workers contain much 10-hydroxy-Δ^2-decenoic acid, which is abundant in the food they give to larvae. Wax and stored pollen were tested for the presence of strongly acid substances, but none were found, so worker bees are unlikely to use the secretion of their mandibular glands when working wax or storing pollen.

The mandibular gland contents of older bees have a strong smell,

and repelled foraging bees when added experimentally to a dish containing food. (Simpson.).

Pollination

Studies of the behaviour of honeybees visiting apple, apricot, peach, pear, plum and sweet cherry flowers showed that, when seeking pollen only from a flower, a bee scrabbled over the anthers, pulling at them with legs and mandibles. When collecting nectar a bee stood either on the stamens or petals and pushed its tongue and head towards the nectary. About 50% of the bees seeking nectar collected pollen as well, apparently incidentally, when it was abundant. On any one trip a bee usually collected either pollen only, nectar only or nectar with some pollen incidentally. The proportions of foragers behaving in these three different ways varied, not only from day to day, but also at different times on the same day. Except on pear trees, bees that were collecting pollen only visited more flowers per minute than those that were collecting nectar.

Bees that scrabbled for pollen, and nectar-gatherers that approached the nectaries while standing on the stamens, touched both anthers and stigma and were probably efficient pollinators, but nectar-gatherers that stood on the petals and approached the nectaries from the side were inefficient, as they touched only the anthers of the apricot, pear, cherry, plum and pear flowers, which had spreading filaments, and did not even touch these in the apple flowers which had upright filaments. In apple varieties with relatively short and thin filaments most of the nectar-gatherers preferred to push their way to the nectaries from the top of the flower, but in varieties with thicker and longer filaments they preferred to approach the nectary from the side. The filaments of Bramley Seedling were so tall and thick that would-be nectar-gatherers could not reach the nectaries either from the top or the side of the flower. In this variety, therefore, it is unlikely that nectar-gatherers are of much use as pollinators, but, of course, pollen-gatherers make excellent pollinators, both in this and other varieties.

On average a bee visited slightly under two trees per trip and tended to move to a tree immediately adjacent to that on which it started working. It is possible, therefore, that when more than two rows of trees of the main variety are planted between rows of a polliniser variety the centre row, or rows, sometimes get pollinated less than those adjacent to the polliniser. In orchards where adjacent rows of trees were farther apart than adjacent trees in a row the bees tended to move more readily between trees in the same row than between trees in adjacent rows. (Free.)

Bee Diseases

European Foul Brood disease

As *Streptococcus pluton* survives long periods (now known to be at least 3 years) in dried smears of infected larval mid-guts, it was possible to study further methods of isolating it *in vitro* from natural material, and to observe its behaviour, which changes somewhat in subculture. Isolation was often better in deep agar (1%

Difco yeast; 1% glucose; 1·36% KH_2PO_4; 2% agar; pH to 6·6 with KOH and sterilised at 116° for 20 minutes) incubated at 35° in a normal atmosphere, than on plates of the same agar incubated anaerobically with CO_2. It was consistently better in deep agar sterilised without glucose than with. In medium made by mixing separately autoclaved agar and 20% glucose solution containing 0·01% phosphoric acid, growth was often in two bands: one reached from, or near, the bottom of the tube to a sharply defined limit about a centimetre from the surface, and this was followed by a narrow band above it and separated from it by a blank interval a few millimetres wide. The number of cells in the inoculum did not greatly influence these phenomena, which also appeared earlier, but in the same form, when CO_2 was added to the atmosphere. Double-banded growth also arose from inocula composed of single colonies from pure subcultures. Heat-degradation products of glucose seem to stimulate growth, as Seitz-filtered glucose solutions gave uncertain growth which also had poorly demarcated limits and was not in separate bands.

Isolation tests in plates, anaerobically $+CO_2$, have recently given erratic results, and growth has often failed completely, whereas simultaneous tests with deep agar, as described above, gave satisfactory growth. The reason for these differences remains obscure, but is suspected to be variable amounts of inhibitory substances produced in the media; incorporating soluble starch (1%) invariably gave excellent isolation, even from very dilute inocula, presumably by neutralising the inhibitors. Isolation in deep agar was also greatly improved by adding starch. Subcultures seemed much less sensitive to the inhibitors. With starch, a rare strain of *S. pluton* was isolated and propagated on media containing little phosphate (0·01*M*).

Strains of *S. pluton* from diseased larvae collected in Louisiana and New York States, U.S.A., responded to the media described above in the same way as *S. pluton* collected in the United Kingdom, but they are more sensitive to the suspected inhibitors.

Isolation and propagation of Swiss strains of *S. pluton* at Liebefeld, Switzerland, have been found to be facilitated by using the original Rothamsted medium with added trace elements (a supplemented Hoagland's solution), but isolation and growth of all strains of *S. pluton* tested at Rothamsted, on media with or without starch, were not influenced by this modification.

After finding that European Foul Brood (EFB) disease and larval nutrition are closely involved, newly formed healthy pupae were weighed throughout the season to find out what variations occurred. Significant fluctuations were observed, with the same trends, simultaneously in different colonies, indicating an environmental effect. Weight decreased greatly in May, after a maximum at the end of April, coinciding with intense foraging activities and the first major outbreaks of EFB in Britain in the season. This is compatible with experimental results suggesting that acute outbreaks of EFB coincide with rapid increases of foraging and brood rearing activity, particularly after some brood restriction, when larvae may receive less glandular food than usual from the workers. Pupal weights were lowest at the end of July, and increased during

late summer and autumn, even though colonies were by then reluctant to rear much brood, as shown by the disappearance of many eggs and young larvae whose positions had been recorded. (Bailey.)

Nosema disease

Laboratory experiments were made to test claims that *Nosema apis* infection can be successfully treated by feeding colonies with common salt in syrup. Sodium chloride, in various concentrations in syrup, was fed to caged adult bees and 0·1% (w/v)—i.e., $\frac{1}{40}$ the concentration alleged to have been effective—was highly toxic to the bees. Controlled tests with salt in concentration of 0·1% and lower, non-toxic concentrations, on artificially infected caged bees, had no effect on the number of spores that developed in the bees' mid-guts. Toxic materials may, of course, kill mostly the older heavily infected bees and so lower the percentage of bees infected, but even if this is so, it seemed unlikely to be of net benefit to a colony.

Similar tests were made with the following materials, some of which have been reported by various investigators to have had beneficial effects in field trials (trade or abbreviated names, followed by manufacturers' names in parenthesis are used): Pentamidine isethionate, Propamidine, Embazin (May & Baker); Paludrine, Mepacrine (Imperial Chemical Industries); Daraprim (Wellcome Laboratories); Camoquin (Parke Davis & Co.); Griseofulvin (Glaxo Laboratories). All proved ineffective against *Nosema apis*. Merthiolate (Eli Lilley & Co.) and Nosemack (Heinrich Mack) had identical effects: at concentrations higher than 2 mg.% they suppressed infection, but they also shortened the lives of the bees significantly. (Bailey.)

STATISTICS DEPARTMENT

F. YATES

Muriel E. Davis resigned during the year to take up a post with the Department of Agriculture, New Zealand. S. F. Buck, Agricultural Research Council Scholar, joined the Pig Industry Development Authority on completing two years' research for a Ph.D. New appointments were: J. R. Davis from the National Coal Board, A. Frater from the R.A.F. Bomber Command Development Unit and M. P. Vessey from University College London Medical School.

Healy returned in July from a year's visit to the U.S.A., most of which was spent at the Bell Telephone Laboratories, Murray Hill, N.J. While there he gained valuable experience working on a large electronic computer, the I.B.M. 704. Church spent two months in Kenya at the invitation of the East African Extract Corporation Ltd., investigating methods of sampling pyrethrum. Leech spent two months in Southern Rhodesia planning a survey of the fertility of beef cattle. Yates attended an International Biometric Meeting organised by the Société Adolphe Quetelet as part of the Centenary Celebrations of the Institut Agronomique, Gembloux, and gave a paper on the use of electronic computers in the analysis of experimental results (12.4). Leech attended a Symposium on Quantitative Methods in Pharmacology held by the Biometric Society in Leyden.

Yates was awarded the Guy Medal in Gold of the Royal Statistical Society; he was appointed President of the British Computer Society for 1960/61 and Chairman of the Committee on Agriculture of the Ministry of Science (formerly the Sub-Committee on Agriculture of the Natural Resources Committee, Lord President's Office).

Work started early in 1961 on an additional building for the Department, which will house the new electronic computer and provide much-needed accommodation for staff.

THE ELECTRONIC COMPUTER

The Elliott 401 continued to give satisfactory service until July, when a bearing of the magnetic disk store failed. The manufacturers did a good job of work in replacing this store by a drum store of the type that is fitted to the 402. This was repaired in a month, but unfortunately there has since been recurrent trouble from interference between the motor driving the drum store and the electronic circuits. A further two weeks were wasted in investigation of the trouble by the manufacturers, but it has not yet been cured.

The breakdown of the machine and the subsequent troubles have seriously interfered with the work of coupling up the magnetic tape unit to the computer, and although considerable progress has been made, we still have a fair amount to do.

In spite of these troubles, we have been fairly successful in coping with current demands, but at the cost of considerable strain to

members of the Department, and particularly to the engineering staff. We have now introduced for a trial period a regular system of overtime, working from 5.30 p.m. to 9.30 p.m. for three nights a week, which it is later hoped to extend to five nights a week. Previously overtime running in the evenings was almost wholly done by scientific staff. Systematic overtime working will, of course, only be possible if the computer gives reasonably reliable service.

TABLE 1

Record of machine operation for 1957–60

Percentage of time for:	1957	1958	1959	1960 *
System modification	0·6	2·4	0·0	0·2
Scheduled maintenance ...	12·4	13·9	9·4	9·8
Unscheduled maintenance:				
Computer	6·2	2·3	3·1	3·1
Peripheral	1·8	1·5	1·1	0·4
Programme checking	17·8	13·3	8·9	14·8
Programme tape preparation ...	4·8	3·5	1·4	2·6
Production runs	49·8	58·4	73·9	67·2
Abortive efforts:				
Computer	1·3	1·4	0·7	1·6
Peripheral	1·0	1·7	0·8	
Idle time	4·4	1·7	0·7	0·4
Total	100·1	100·1	100·0	100·1
Total hours worked	2,622	2,869	2,993	2,757
Percentage overtime	32·6%	45·1%	50·8%	55·9%

* 46 weeks.

Table 1 shows the record of machine operations over the last 4 years, excluding the 6 weeks for which the machine was out of commission in 1960. Although there is little difference from previous years in the percentage of total time during which the machine was recorded as working incorrectly or out of commission (apart

TABLE 2

Numbers of replicated experiments analysed in the department

	Number of experiments: By hand	On computer	Total	Number of variates on computer
1934	115	—	115	—
1951	437	—	437	—
1955	384	419	803	834
1956	181	683	864	1,701
1957	98	1,253	1,351	5,041
1958	182	1,664	1,846	6,260
1959	67	2,649	2,716	11,102
1960	85	3,687	3,772	11,147

from the 6 weeks referred to above), there was a considerable difference in efficiency before and after the breakdown. Of the 85 hours spent on unscheduled maintenance, for example, 74 occurred in the last 5 months of the year. Moreover, some time that has been booked to production for survey analysis should have been included in abortive effort.

The main increase in work this year has been in survey analysis,

largely as a result of completing the General Survey Programme referred to below. 25% of the total production time was used for survey work. If machine time is available a further substantial increase in survey work may be expected in 1961.

The number of experiments analysed on the machine (Table 2) again increased, because of a large series of very simple fertiliser trials (894 trials) analysed for Pakistan, and of the fact that part of this series (523 trials) had to be re-analysed because we were not informed that the treatments had been changed. The number of variate analyses is almost the same as last year.

Replacement of the Elliott 401

The replacement of the Elliott 401 has been under consideration for some time, and it has now been decided to install a Ferranti Orion. An order has been placed, and delivery has been promised for the autumn of 1962. The Orion is a considerably larger and faster machine than the 401. It will have a computing speed of the order of 25–50 times that of the 401, and input and output of information with the ancillary equipment we envisage will be of the order of 10–20 times that of the 401.

Certain items of equipment for the input and output of information are still under discussion, but the installation will probably be as follows:

Central computer

4,096 words of immediate access storage
32,768 words of drum storage
Built in floating-point facilities

Magnetic tape

Two Ampex units

Input

Paper tape and punched cards

Output

Paper tape, punched cards and line printer

One important advantage of a larger and more modern machine is that less effort is required for programming. During the last 5 years much progress has been made in the simplification of programming, and in the art of constructing programmes which are simpler to use and cover a wider variety of problems of the same general type.

(a) *Improvement in order codes*

The order codes of the more modern machines are much more straightforward and simple to use than those of the early machines. In part this is a consequence of improvements in electronic techniques, in part from recognising the importance of lightening the programmer's task if a computer is to be used effectively. These simplifications are greatest in large machines.

(b) *Autocode facilities*

The use of autocodes is rapidly spreading. An autocode enables the operations required to be specified in simple form; thus mathematical operations can be specified by ordinary mathematical formulae. This specification is translated into the machine code by means of a programme held in the machine. Effective autocodes can only be developed on large machines. (Ferranti have provided an autocode for the Mercury, and propose to provide a similar autocode for the Orion.)

(c) *Generality of programmes*

Many statistical computations, such as the analysis of experiments, the analysis of surveys and much multivariate work, are largely standardised. Within these standard types, however, there are many variants, and it is important that programmes should be such that all variants normally encountered can be called for without any special programming. Such general programmes are necessarily complex, and can only be effectively written for a large machine. Our 401 programmes for the analysis of experiments are too inflexible to deal conveniently with exceptional designs, and some designs have not been programmed at all. These defects were not of great importance initially, when the total number of experiments analysed was small, but are serious now the load has increased tenfold. Similarly in the analysis of surveys, machine limitations prevent the construction of a programme which is sufficiently powerful and speedy to deal efficiently with large, complex surveys.

(d) *Ease of specification*

A programme must not only be sufficiently general. It is also important that the specification of exactly what is required in any particular analysis is itself simple, for this makes the specification easier and substantially reduces errors. Equally, in the presentation of results it is important to provide a good lay-out and introduce printed headings where required, particularly when the results have to be sent to research workers in other stations. Here again adequate storage and speed are required; our 401 programmes leave much to be desired in these respects.

(e) *Floating-point arithmetic*

Although in much statistical work fixed-point arithmetic can be used, this inevitably causes programming difficulties which are entirely avoided by the use of floating-point facilities. Fixed-point arithmetic also complicates the specifications of the work required, because instructions regarding scaling must often be included in these specifications. To evaluate complicated mathematical functions, it is almost essential to work in floating point. This can be done on a fixed-point machine, but only with considerable loss of speed.

Programming has been a major limiting factor in using the 401. Although theoretically much more work could be handled by round-the-clock working, this would require a considerable increase in programming staff, and from the national point of view it would be

very uneconomic to devote scarce programming ability to the programming of such a slow machine, even if the necessary staff could be obtained.

The greater ease of programming and the availability of autocode facilities and easily used general programmes for such work as the analysis of experiments and surveys should enable statisticians at other research stations to participate much more directly in programming the Orion for their own problems than has been possible with the 401. We shall make every effort to encourage this co-operative approach.

Programming Developments

We reported last year that a general system for the specification of survey analyses had been worked out. The view was then expressed that it would not be practicable to write a programme for the 401 which would interpret these specifications directly, so avoiding special programming for survey analysis. Further investigation showed, however, that a useful general programme could be constructed, and this has now been done. (Yates and H. R. Simpson 12.23, 12.26, 12.27.) This programme, though slow, has revolutionised the analysis of surveys on the computer. It will also serve as a prototype for a faster and more sophisticated programme for the Orion.

The construction of the general survey programme has suggested a similar approach to the analysis of experiments. This may provide a solution to the analysis of long-term experiments and one-year experiments with exceptional and rarely occurring designs. A preliminary investigation on these lines has been started. (Yates and Gower.)

No further work has been done on the development of a communications language suitable for statistical programmes; it was decided that the change of scale between the 401 and the Orion was such that it would be more profitable to construct much more general programmes for the Orion than to attempt to transpose the programmes we at present use on the 401. We are, however, investigating the possibility of writing a programme for the Orion that will enable it to accept 401 programmes, so that as an interim measure little-used programmes can be used on the Orion without any re-programming. This task is more complicated than appears at first sight, mainly because in B-modification on the 401 the whole of the order is modified, and thus under certain circumstances the address of the next order or the operation performed may be changed. The simplest procedure is to use a straight simulation routine in which each order of the 401 is re-interpreted every time it is obeyed, but this would be very slow; a combination of translation and simulation appears to be what is required, simulation being used for modified orders when the contents of the modifying register are such that the address of the next order or the operation is changed. (Bonsall and Rees.)

We may also write a routine for simulating Orion operations on the 401. Such a routine will enable Orion programmes to be tested before our machine is installed. It will be worth while to do this

only if adequate facilities for testing Orion programmes cannot be obtained elsewhere.

A set of programmes has been written for classifying different types of organism according to the similarities revealed by a set of tests. (Gower.) This problem has attracted attention in various quarters, and a method was recently proposed by Dr. P. H. A. Sneath, and tested on some data on strains of bacteria, using a computer. (The application of computers in taxonomy, *J. gen. Microbiol.* 1957, **17**, 201–226.) Essentially the method consists of calculating coefficients of similarity between every pair of strains and then grouping the strains in such a manner that, for any given level of similarity, each strain in a group has a similarity greater than the given level with at least one other member of the group; this grouping is performed successively at decreasing levels of similarity until all the strains are grouped together. Although simple in principle, the procedure involves heavy computing and a considerable amount of classification work when the number of strains and tests is at all large. The method appears to be of wide interest as we have already had requests for:

(1) Taxonomic grouping of a number of types of bacteria. (Dr. M. Pleasance, Low Temperature Research Station.)

(2) Taxonomic grouping of a number of types of fungi. (Miss G. W. Waterhouse, Commonwealth Mycological Institute.)

(3) Grouping of Pacific islands by the species of birds occurring in them. (Mr. I. C. J. Galbraith, Natural History Museum.)

(4) Grouping of psychiatric patients by their various symptoms. (Dr. A. E. Maxwell, Maudsley Hospital.)

Of the other general programmes developed during the year, the following may be mentioned:

(1) Programmes for centroid factor analysis and for rotating and plotting factor loadings (Healy).

(2) An auto-covariance programme and a Fourier transform programme for the estimation of power spectra in time series. The construction of recurring digital filters for time-series work has also been investigated (Healy).

(3) The fitting of constants to large two-way tables which are beyond the capacity of our present programme (Bonsall).

(4) A general programme for the fitting of Chebyshev polynomials to observed data (Bonsall).

(5) A programme for determining the distribution of distances between pairs of diseased plants in a field. This forms part of an investigation in the spatial spread of disease in crops (Gower, with A. J. Gibbs, Plant Pathology Department).

Experimental Design and Analysis

The results of recent fertiliser trials on potatoes were studied and compared with those of earlier series. Although there appeared to be no large changes in response to the standard nutrients, the study revealed several new facts and in particular showed that there were

not only large interactions between nutrients but also that the shape of the response curves varied considerably at different levels of the other nutrients. Evidence was obtained that the exponential form of the response curve is unsatisfactory and that yield may be decreased by excessive dressings (Boyd (6)). The responses of potatoes to manuring in the peaty Fenlands and their relation to soil types were also examined and reported, in collaboration with the National Agricultural Advisory Service. (Dr. N. H. Pizer *et al.*, and Boyd (12.21).)

Recent experiments on nitrogen responses of cereals were studied for the National Agricultural Advisory Service (Lessells). Nitrogen response is very variable and sometimes negative, the following factors being important: yield without nitrogen, time of sowing, time of application, previous crop, nutrient status of soil, and disease incidence.

Current fertiliser practice was examined in the light of the results of manurial experiments on potatoes, sugar beet and cereals. The large variations that occur in fertiliser applications from farm to farm appear to be largely unrelated to crop requirements. However, differences in average applications from districts known to have substantially different requirements are small (Boyd (12.8)).

At the request of the Soil Fertility Committee of the Soil Chemists' Conference, the correlation of soil analysis with crop responses to fertilisers was studied and a joint paper is to be published (Boyd and E. P. Simpson).

A survey of long-term agricultural field experiments has been started. So far this includes studies of the structure of errors, the value of an initial period of uniform treatment in improving the accuracy of subsequent results and an assessment of the value of time-trends as indicators of the long-term effects of treatments (Patterson).

The results to date of six long-term experiments on Experimental Husbandry Farms on the use of various forms of phosphatic fertiliser were summarised (Patterson), and reports prepared for the Animal Experiments Sub-Committee on the preliminary results of the Beef Progeny Tests and Beef Carcase Assessment from the experiments done at Experimental Husbandry Farms (Boyd, Frater). We have analysed many other experiments, both on crops and animals, for the National Agricultural Advisory Service, and advised on experimental design (Dunwoody, E. P. Simpson, Frater and Turner). An article was written on the planning of series of experiments (Boyd (12.7)).

The Bulletin on changeover designs by Patterson and Professor H. L. Lucas (Institute of Statistics, North Carolina), referred to in the 1958 Report, was completed (12.20).

An analysis of some experiments on the effects on the growth of *Vicia* with light and temperature treatments on both roots and shoots has been completed for Professor W. T. Williams, Botany Department, Southampton University (Gower). This involved fitting constants and a covariance analysis between two variates, both with incomplete data.

Surveys

Surveys of fertiliser practice were made by the N.A.A.S. Soil Chemists in 10 districts of England and Wales in 1960. Field work was delayed by the wet summer and by foot-and-mouth disease, but four districts have been analysed. Parallel surveys in Scotland were made in six districts, of which four have been analysed. Two summary papers on the 1957–58 Survey of Fertiliser Practice were completed (Boyd, Church and Hills (12.9), (12.12)), as was a report on the survey of fertiliser practice on market garden crops of the Evesham–Pershore district.

The report on the 1958 Maincrop Potato Survey, done jointly with the National Institute of Agricultural Engineering and the Potato Marketing Board, was published by the Potato Marketing Board (Mr. J. K. W. Slater, Church and Hills (12.22)).

Analysis of the Grassland Survey of England was completed for the Grassland Research Institute (H. R. Simpson and Mr. C. D. Kemp).

The herbicide survey, started in 1959 in collaboration with the A.R.C. Unit of Experimental Agronomy, Oxford, was extended to a further five districts in 1960 (Church).

The analysis of the first National Survey of Disease in Dairy Cattle, covering the year 1957–58, was completed and a report published (Leech, Davis, Vessey (12.18)), and the 1958–59 data were analysed (Vessey). Field work started on a survey of *Brucellosis* in dairy herds in conjunction with the Ministry of Agriculture. A preliminary national survey of losses in breeding ewes was analysed (Davis), and the field work of a second more detailed survey is now completed.

Commonwealth Work

We continued our advisory work for Commonwealth countries and analysed many experiments on the computer (Vernon and Turner). The 1959–60 results of the co-operative fertiliser trials on rice in the State of Bihar, India, were analysed, and a combined analysis of the 4 years' results was also made; this provided an interesting exercise in the analysis of the results of a large series of trials extending over several years, and it is intended to publish a paper on the methods adopted (Yates and Gower). A further year's results from a similar and simpler series of experiments in Pakistan were analysed (Gower). The analysis of a long-term experiment on coconuts for the Coconut Research Institute, Ceylon, was completed by Dr. T. Eden (working in this Department) and Gower.

A report was prepared on the results of a capsid control experiment run jointly by the Shell Chemical Company and the Western Nigerian Ministry of Agriculture. Similar data from work in Ghana is now being examined (Vernon).

We are collaborating with Mr. J. L. Gregory, of the Federal Agricultural Research Organisation of Nigeria, in the examination of a voluminous set of data from light traps and insecticidal studies of yam beetles (Vernon and Morris).

At the request of the East African Extract Corporation, supported

by the Department of Agriculture and the Pyrethrum Board of Tanganyika, Church visited Kenya to investigate large-scale commercial methods of sampling dried pyrethrum flowers. An unbiased method of reference sampling was developed suitable both for direct use in experimental work and as a standard for testing the adequacy of routine commercial sampling. The mechanical sampling method used by the East African Extract Corporation was tested against this standard (12.11).

Four Commonwealth workers worked in the Department for varying periods. Leech spent 2 months in Rhodesia, planning a Federal survey of the fertility of beef cattle.

Other Work

Of the many miscellaneous problems from Rothamsted and other research institutes and organisations dealt with by members of the Department, most of which have involved the use of the computer, the following may be mentioned:

1. A comparison of theoretical and empirical results for some stochastic population models (Professor M. S. Bartlett, Gower and Dr. P. H. Leslie (12.5)).

2. The derivation of marginal percentages in quantal data with disproportionate frequencies, analysed by use of a transformation (Yates (12.25)).

3. A method of dealing with incomplete multivariate data, suitable for use on an electronic computer (Buck (12.10)).

4. Continuation of the investigation on the multiple transfer method of sampling (Gower with A. J. Gibbs, Plant Pathology Department (12.15)).

5. A programme for Darroch's capture–recapture method (described in *Biometrika*, **46**, 349–351) for F. Raw, Entomology Department, and Dr. P. H. Leslie, Oxford Bureau of Animal Population (H. R. Simpson).

6. An investigation of the joint action of four poisons, following the methods of Hewlett and Plackett. Two models for the joint action of poisons based on the known responses of each poison separately both gave satisfactory agreement with experimental results (Gower with R. M. Sawicki, Insecticides Department).

7. Biological studies of the wheat-bulb fly (*Leptohylemia coarctata* (Fall)) were continued in collaboration with the Entomology Department (Morris, R. M. Dobson and D. B. Long (12.13)).

8. Least-squares estimation of components of variance in genetical data. This analysis was undertaken for the Department of Genetics, Birmingham University, using a corrected form of the methods applied by Mr. J. A. Nelder, National Vegetable Research Station (Bonsall).

9. Fitting of constants and analysis of variance on some non-orthogonal data on herrings for the National Institute for Research in Dairying (Bonsall).

10. A study of foetal growth in the mouse, and an explanation of the inverse relation between number in the litter and

size of young at birth (Healy, with Dr. Anne McLaren and Dr. D. Michie (Royal Veterinary College) (12.17)).

11. The relation of body build to the excretion of 17-ketosteroids and 17-ketogenic steroids in healthy young men (Dr. J. M. Tanner, Mr. R. H. Whitehouse, Mr. A. C. Edgson, Institute of Child Health, University of London, and Healy (12.24)).

12. Research on the effect of temperature on the yield of crops, and on Penman's potential transpiration theory. A paper is being prepared (Buck).

13. Examination of data relating to sulphur dioxide pollution of the atmosphere at Great House Experimental Husbandry Farm. Contrary to what has previously been reported in the literature, values recorded by the conventional SO_2 candle method seem to depend on wind speed as well as SO_2 concentration (Vernon and Mr. C. H. Mudd).

14. The effects of heating and lighting variation on the ripening of tomatoes (Gower with Dr. A. J. Cooper, Glasshouse Crops Research Station).

In addition, work on medical and other problems has been undertaken for the London University Institute of Child Health, the Imperial Cancer Research Fund, the Medical Research Council, the National Survey of the Health and Development of Children, the National Foundation for Educational Research, the Institute of Criminology, the Home Office and the Prison Commission.

Mr. N. E. G. Gilbert of the John Innes Institute continued his work on animal breeding problems in conjunction with the Animal Breeding Research Organisation; in particular, the analysis of data from pig progeny testing stations of the Pig Industry Development Authority was completed with the estimation of genetic components of variance and heritabilities. Latent vectors were used successfully to summarise the numerous genetic correlations.

Papers 12.14, 12.16 and 12.19 relate to previously reported investigations.

FIELD EXPERIMENTS SECTION

G. V. Dyke

The field experiments at Rothamsted and Woburn are controlled by the Field Plots Committee: F. Yates (Chairman), G. V. Dyke (Secretary), F. C. Bawden, G. W. Cooke, H. V. Garner, P. H. Gregory, J. R. Moffatt, C. A. Thorold, R. G. Warren and D. J. Watson. During 1960 the Committee discussed with R. Hull some of the experiments (mainly long-term) proposed for Broom's Barn Experimental Station.

Table 1

	Grain	Roots	Hay	Grazing	Total
Classical experiments:					
Rothamsted ...	238	—	130	—	368
Woburn	50	—	—	—	50
Long-period rotation experiments:					
Rothamsted ...	442	291	199	96	1,028
Woburn	181	283	55	12	531
Short-period experiments:					
Rothamsted ...	694	160	—	—	854
Woburn	271	49	—	—	320
Total	1,876	783	384	108	3,151

Table 1 shows the total number of large plots harvested by the staff of the two farms and how they were distributed between different crops and experiments of different types. Three hundred and fifty-nine large plots were managed but not harvested by the farm staff. In addition, the departments laid down 158 large plots and 1,228 micro-plots; the total was 4,896.

Broadbalk

The wheat was drilled in October in good conditions and came well through the winter. By harvest-time vetches (*Vicia sativa*) were abundant on some plots and caused severe lodging on a few. On the remaining plots lodging was widespread but generally slight. The investigation of the relative efficiency of three methods of sampling the grain to determine the proportion of weed seeds and rubbish was continued.

Hoosfield Permanent Barley

Spraying against coltsfoot (*Tussilago farfara*) continued (see *Rep. Rothamst. exp. Sta.* for 1959, p. 159) with apparently good results. After harvest the whole area was sprayed with dalapon to control small patches of couch grass (*Agropyron repens*). The areas sprayed in autumn 1959 had much less couch in 1960.

At harvest four separate cuts were taken from each plot of full width (but two each from plots 6–1 and 6–2, three each from 7–1 and 7–2). The cuts were marked by blank rows left at sowing.

Except on a few plots straw yields were taken from only one cut per plot.

Park Grass

All yields were measured this year by the flail-type forage harvester, and a scheme was established for the future use of this machine. Sample strips 40 inches wide are cut along the length of each plot, two from narrow plots, four from wide plots. The sample strips will occupy different positions for four seasons, then repeat the cycle. In one season the same strips are used to estimate yield of first and second cuts. Both are weighed fresh and sampled to determine dry matter. At the first cut the remainder of the area is cut by mower and the hay is made on each plot as in the past, but no weights are taken. At the second cutting the whole of the produce is cleared by the forage harvester after the cutting of the sample strips.

The variation between sample strips of the first cut of 1960 was greater on unlimed than on limed halves. If the differences between samples within each plot are used to estimate sampling error the standard errors per plot mean are:

	Not limed		Limed	
	Fresh weight (cwt. per acre)	%	Fresh weight (cwt. per acre)	%
Plots with 4 cuts ...	4·3	9	3·0	5
Plots with 2 cuts ...	4·0	8	2·8	4

These results suggest that the sampling method adopted in 1960 gave reasonably precise estimates of the plot yields. Unless future results show very much more variation between samples, there seems no reason why the technique should not be completely satisfactory for estimating the Park Grass yields.

Exhaustion Land

Throughout the season the differences between the plots were much less than in recent years. Yields also were relatively uniform, the strips without effective manurial residues yielding more than usual.

The stubble was sprayed with dalapon against couch grass (*Agropyron repens*).

Garden Clover

This year each sub-plot (with and without K) was subdivided for a test of molybdenum applied as a spray. The clover grew very irregularly, and there was no visible effect of molybdenum.

Barnfield

Manures were applied as usual, but the land was fallowed to control weeds, including couch grass (*Agropyron repens*). Rotary cultivation and weed-killer spray were both used. In 1961 the fallow will be continued, and manures applied, to prepare for an investigation of the cumulative effects of the long-term treatments.

Potato experiments

Potato lifting was much delayed by excessive rain, and mechanical lifting became impossible. On three experiments potato plots were therefore sampled and yields estimated by hand-digging areas (one per plot) of 0·0035 acres. The standard errors per plot were remarkably small (4·6, 5·3 and 6·1% of the respective mean yields).

Green Manuring at Woburn

The long-term Green Manuring Experiment at Woburn (Stackyard, Series A) since its revision in 1955 has given much greater yields of barley where trefoil or ryegrass was ploughed in (sown after early potatoes in the previous season).

Mean of 6 seasons, 1955–60

Barley grain, cwt./acre

	Fertiliser to barley (cwt. N/acre)	
	0·23	0·46
No green manure	18·4	23·6
Trefoil ploughed in in autumn	26·5	28·3
Trefoil ploughed in in spring	30·0	31·4
Ryegrass ploughed in in autumn	22·4	26·4
Ryegrass ploughed in in spring	25·4	31·2

Green manures have also slightly increased the yield of early potatoes.

The interpretation of these effects is complicated by several features of the design of this experiment; the green manuring effects shown in the table contain unknown but probably small residual effects of treatments applied before 1955. Two short-term experiments were laid down in 1960 to investigate the value of green manures and the interaction of their effects with those of nitrogen fertiliser applied directly.

(a) *Stackyard, Series C*

Barley in 1960, followed by sugar beet in 1961. All combinations of two factors will be tested:

(i) Green manures undersown in barley and ploughed in in spring: none, trefoil, ryegrass, ryegrass with 0·6 cwt. N as "Nitro-Chalk" applied after harvesting barley.
(ii) Four levels of N applied to sugar beet.

(b) *Lansome Field*

Early potatoes in 1960, barley in 1961. All combinations of two factors:

(i) Green manures sown in the open after lifting potatoes: none, trefoil, ryegrass, ryegrass with 0·6 cwt. N as "Nitro-Chalk" applied in seedbed.
(ii) Four levels of N applied to barley.

On both experiments the trefoil failed to make vigorous growth, apparently because of poor nodulation (see p. 86).

Report on a Series of Field Experiments Testing Winter *v.* Spring Field Beans

by J. R. Moffatt

Winter beans at Rothamsted and Woburn have always been a rather hazardous crop because of risk from damage by birds during the autumn and winter, and because of their susceptibility to frost and to chocolate spot disease (*Botrytis* spp.). Spring beans, though potentially lower-yielding, are far less liable to damage from these causes, but they are more susceptible to attack by bean aphids (*Aphis fabae*), which, in a bad year, can ruin a crop. Systemic insecticides can control this pest and make the crop more reliable.

A series of experiments was started at Rothamsted and Woburn in 1956 in conjunction with the National Institute of Agricultural Botany, to compare the yield of the two types of beans over a period of years and to test the effect of spraying against bean aphids (*Aphis fabae*). The experiments also tested two levels of fertilisers. The Woburn experiments were on heavy land.

In each year there were three blocks of four whole plots each; the plots were split into three for broadcast treatments of phosphate and potash and pairs of whole plots were sprayed. The varieties were tested on whole plots with the PK treatments partially confounded. The levels of phosphate were none; 0·5; 1·0 cwt. P_2O_5/acre as superphosphate, and of potash none; 1·0; 2·0 cwt. K_2O/acre as muriate of potash. "Metasystox" was the insecticide applied in 40–80 gallons of water per acre. The same strain of winter beans, S.Q. Giant, was used throughout the series at a seed rate of 275–300 lb./acre. The spring variety Albyn Tick was drilled each year except 1959; the seed rate was 200 lb./acre except in 1957, when 150 lb./acre was used. In 1959 the variety was Granton, sown at 275 lb./acre because it has larger seed than Albyn Tick. The seed was drilled in rows 22 inches apart and planted as deeply as possible; the depth of drilling varied between 2 and 4 inches according to the condition of the ground. All plots were harvested by combine-harvester, and yields are corrected to 85% dry matter.

Table 1

Grain: cwt./acre—Rothamsted

Year	Winter			Spring		
	No Spray	Sprayed	Diff.	No Spray	Sprayed	Diff.
1956	17·9	19·0	+1·1	16·1	17·8	+1·7
1957	32·4	34·3	+1·9	7·6	18·7	+11·1
1958	12·8	10·6	−2·2	14·4	14·5	+0·1
1959	26·6	28·8	+2·2	13·9	18·8	+4·9
1960	34·3	—	—	20·5	23·7	+3·2
Mean of 4 years						
1956–59 ...	22·4	23·2	+0·8	13·0	17·4	+4·4

Full agricultural details of these experiments, and yields, are given each year in Results of Field Experiments.

At Rothamsted the unsprayed winter beans outyielded both the unsprayed and sprayed spring variety in 4 out of the 5 years.

In the other year, 1958, which had an exceptionally wet summer, chocolate spot disease (*Botrytis* spp.) appeared early in the winter crop and spread rapidly. Both sowings grew tall, and the passage of the sprayer through the winter crop did appreciable damage; this crop also lodged badly. In 1960, a wet year with a medium aphid infestation, the winter beans grew tall and were not sprayed because the crop would have been damaged.

In the three years when winter beans were sprayed without damaging them much, yield was increased slightly (1·7 cwt./acre).

TABLE 2

Grain: cwt./acre—Woburn

Year	Winter 0	Winter Sprayed	Winter Diff.	Spring 0	Spring Sprayed	Spring Diff.
1956	—	—	—	15·4	17·9	+2·5
1957	16·9	23·3	+6·4	8·0	8·7	+0·7
1959	27·4	30·0	+2·6	23·3	17·8	−5·5
Mean of 2 years 1957–59 ...	22·2	26·6	+4·4	15·6	13·2	−2·4

In all 5 years the spring beans benefited from spraying, the increased yield ranging from 11·1 cwt./acre in a year of severe aphis infestation to 0·1 in a year of light infestation.

The Woburn results are less consistent, although the general trends are similar. In 3 of the 5 years the experiment had to be wholly or partially abandoned because birds so severely damaged the winter-sown crop, despite deep drilling and the use of explosive bird-scarers; the damage happened over many weeks.

The unsprayed winter beans yielded more than the sprayed or unsprayed spring beans in both years, and the increase from spraying the winter variety was more (4·4 cwt./acre) than at Rothamsted.

TABLE 3

Grain: cwt./acre—Rothamsted

Mean of 4 years 1956–1959

	P_2O_5 (cwt./acre)			K_2O (cwt./acre)			
	0	0·5	1·0	0	1·0	2·0	Mean
Winter	22·6	23·0	22·7	21·5	23·5	23·4	22·8
Spring	15·6	15·2	14·8	15·2	16·0	14·6	15·3
Mean ...	19·1	19·1	18·8	18·4	19·8	19·0	19·0

The mean yield of the spring variety is 2·4 cwt./acre lower on the sprayed plots than the unsprayed, partly because an early and heavy infestation of bean aphids in 1957 severely damaged the spring crop before it was sprayed in early June. The less-susceptible winter crop, however, benefited appreciably from spraying at this time. In 1959, with few aphids and a lush spring crop, the damage caused by the passage of the sprayer exceeded the benefit from the spray. In 1957 the spring beans also suffered severely from drought and weed competition in ground too hard to hoe.

In none of the four years, 1956–59, was there any significant response at Rothamsted to phosphate. Winter and spring crops

responded in 1956 and 1957 to the lower level of potash, the winter crop responding more than the spring; there was no further increase from the higher level of potash.

Because broadcast phosphate gave no response it was omitted from the 1960 experiment and a single level of potash (0·74 cwt. K_2O/acre) placed near the seed was tested, but it gave no significant response. It increased the winter-bean yield from 34·1 to 34·6 cwt./acre and the spring bean from 21·7 to 22·5 cwt./acre.

At Woburn the only significant increase to phosphate (3·5 cwt./acre) was on a rather variable site with the winter beans in 1959. On all other occasions phosphate tended to lower yields. The lower level of potash always gave an economic return, and in 1959 the higher level gave a further increase in yield.

TABLE 4

Grain: cwt./acre—Woburn

Mean of 2 years 1957 and 1959

	P_2O_5 (cwt./acre)			K_2O (cwt./acre)			
	0	0·5	1·0	0	1·0	2·0	Mean
Winter	24·3	26·6	22·3	22·2	25·2	25·8	24·4
Spring	15·8	13·8	13·8	13·1	14·8	15·4	14·4
Mean ...	20·0	20·2	18·0	17·6	20·0	20·6	19·4

In 1956, when the winter beans failed, the yield of the spring-sown crop was decreased by increasing amounts of phosphate but greatly increased by potash. The means of the three spring experiments are:

TABLE 5

Grain: cwt./acre—Woburn

Mean of 3 years 1956, 1957 and 1959

	P_2O_5 (cwt./acre)			K_2O (cwt./acre)		
	0	0·5	1·0	0	1·0	2·0
Spring	16·5	14·7	14·3	12·9	15·3	17·3

The main conclusions from these experiments are:

1. The yield of unsprayed winter beans is consistently higher than spring beans, sprayed or unsprayed, except when chocolate spot disease (*Botrytis* spp.) is severe or birds damage the crop.
2. In areas where bird damage is common, spring beans are the more reliable crop.
3. In most years satisfactory crops of winter beans can be obtained without spraying, but spraying increases yields in years when aphid attack is severe.
4. The spraying of spring beans is nearly always beneficial, providing it is done in time and the crop is not too damaged by the machine.
5. Neither winter nor spring varieties respond to broadcast phosphate, but both respond to broadcast potash fertilisers.

The White Books

by H. V. Garner

From the earliest times hand-written records of operations on the Rothamsted field experiments have been entered in a set of notebooks known by long custom as the " White Books ". These are substantial volumes bound in white vellum having a certain weight and dignity in keeping with the unique material they contain. The most important are those dealing with the classical experiments of Lawes and Gilbert; these, listed in order of date, are as follows:

Broadbalk, 3 vols: 1843–1912; 1912–1957; 1958 onwards.
Geescroft, experiments on leguminous and cereal crops 1847–1886.
Agdell, 1848 onwards.
Hoosfield Barley Experiment, 2 vols: 1852–1939; 1940–1959.
Park Grass Experiment, 4 vols: 1854–1880; 1880–1919; 1919–1959, also 1873 Botanical Notes by W. B. Hemsley.
Various Experiments, 1870–1923: includes Hoosfield Wheat and Fallow 1870–1946 and Rothamsted Garden Clover 1871–1959.
Barnfield Experiments on Sugar beet and Mangold Wurzel, 2 vols: 1871–1931; 1932–1959.

There is no White Book for the early experiments on Barnfield, which started in 1843 and involved in turn white turnips 1843–48, swedes 1849–52, barley 1853–55, swedes 1856–70. The Hoosfield potato experiments and their residual years in cereals are recorded very briefly in the White Book of " Various Experiments ", as are also the early experiments on leguminous crops on the same field.

There is a gap of four years, 1924–27, in which the annual experiments were unrecorded, but a volume was opened for them in 1928, and others have since been added. It happens that the missing period was the one during which the experimental designs developed by R. A. Fisher were first appearing on the Rothamsted fields. At this time, however, the plans and yields of the annual experiments were published in the *Rothamsted Annual Report.*

Books were started for the new long-period rotation experiments as they were begun from 1930 onwards. In all, the existing White Books number 22 volumes. They contain the dates of the chief cultivations, sowing and harvesting; there are also copies of the manure sheets. The progress of the crop is recorded in plot-by-plot observations made early in the season and again just before harvest. These routine entries are enlivened by notes on special happenings, such as freak storms, uncontrollable growth of weeds, epoch-making changes in technique and the very rare instances when manures found their way on to the wrong plots or produce got mixed up before weighing. The entries are quite anonymous, not even initialled; the handwriting is of a very high standard, and some of the manure tables are minor works of art.

There are many interesting notes that bring the old fields to life: thus in the Broadbalk books we read that in 1883: " The plant was thin upon the ground the seed having been sown in the worst seed-

bed as regards tilth that could be imagined, the oldest men on the farm remarking that they had never seen wheat ' go in ' worse, but if advantage had not been taken of that opportunity no other occurred for some weeks afterwards owing to the drenching rains of October and November. The ears of the wheat are however remarkably large and plump berried and the straw is stiff and strong which confirms the old adage that ' wheat sown in the slop becomes heavy in the top '."

Broadbalk, of course, saw many changes of technique: " Season 1901. Crop cut August 1, 2, 3. For the first time in the record of the experiments the crop was cut with a self-binding reaping machine, which did its work remarkably well." Fifty-six years later: " Combine harvesting. This year (1957) all plots were cut by self-propelled combine harvester for the first time. . . ."

Broadbalk has several " dell holes ", the fallen-in chalk pits used long ago to chalk the surface soil. One hole had a different history: " *Zeppelin Raid* (1916). On September 2–3 night a Zeppelin dropped bombs in this locality in the early hours. A bomb was dropped in Broadbalk Field on Plots 5 and 6 making an enormous hole. The clay was scattered in all directions. The hole measured 18 feet across and 11 feet in depth about $\frac{2}{3}$ on Plot 6 and $\frac{1}{3}$ on Plot 5. Beyond burying one of the shocks (10 sheaves) on Plot 6 and breaking a few panes of glass in the cottage windows no other damage was done."

Agdell rotation field carried a patchy crop of wheat in 1883. The note was: " Owing partly to the unfavourable conditions of the seedbed, and partly to the trampling of horses feet during a stag hunt soon after the seed was put in, much of the corn perished in the ground."

The record of Barnfield tells of a long struggle against an exceptionally difficult soil which often gave poor seedbeds for sugar beet and mangolds, and appalling carting conditions. Thus in 1874, when the field was in sugar beet we read: " The land was in a very sticky condition from frost thawing the afternoon of the first day's carting, but in a much worse state the next day. The cart wheels cut into the ground exceedingly, carrying the soil from one plot to another in a fearful manner. It occupied one man the whole day to clean the wheels after arrival at the top of the field."

Mistakes in manuring were exceedingly rare, and when they occurred, or it appeared that they might have occurred, the facts were recorded in the White Books. For example, the notes on the Park Grass Plots in 1867 tell us that: " Mr. Lawes was of the opinion from the appearance of the crop that the nitrates had not been previously sown, he therefore directed them to be put on although the actual table drawn for the sowing of the minerals (in December) had the nitrates entered in it and some of the men thought it had been sown and others that it had not, and an appeal to Robert Dudgeon who was then at the asylum gave no conclusive result."

The reason that mishaps have some prominence in the old White Books is that, as in other walks of life, if things go well no comment is called for. There is abundant evidence of the competence and integrity of the men who tended the field experiments and assembled the original data.

In 1959 the Plot Committee examined the time-honoured recording system and decided that the following additional information should be included for every experiment: (i) numerical results as drawn up by the Statistical Department; (ii) electronic computer sheets giving individual plot yield and other useful data; (iii) field observations by the sponsors of individual experiments; (iv) index of laboratory investigations on soils and produce; and (v) photographs to illustrate special points. The material will be assembled in loose-leaf form and at convenient intervals will be indexed, microfilmed and bound.

THE FARMS

J. R. Moffatt

Rothamsted

The year started with field work well forward as a result of the favourable conditions throughout 1959. The spring and early summer were likewise favourable, but conditions then deteriorated. The hours of sunshine were below average in all except 2 months, and the total deficit for the year was 152·3 hours. In each of the 6 months July to December 1960 rainfall was well above normal, and the total for the year was 36·37 inches, the highest since 1927. Corn harvest was late, but conditions were not as difficult as in 1958, and yields were not seriously affected. Rain fell on nearly every day during October, November and December and totalled 14·60 inches, compared with the average of 8·35 inches. The soil became waterlogged, and field work completely stopped. At the end of the year most of the potato crop was still in the ground, almost no winter crops had been sown and very little land ploughed. Seldom, if ever, has field work been so far behind schedule.

The Effect of Weather on Crops

In the dry autumn of 1959 the field work suffered little interruption from the weather, and most of the ploughing was done by the end of November. The drilling of winter corn and beans for the 1960 crop started early, and was mostly completed by the end of October. Conditions were so good that the acreage of winter wheat was increased beyond that originally planned. A mild, wet spell in December 1959 and January 1960 stopped field work, but ploughing and dung carting finished in the early part of February. The winter was generally mild and damp, and with no prolonged spells of frost or snow.

Spring cultivations started in early March and, despite the few frosts, good seedbeds were obtained. Most of the corn and beans were drilled before the end of the month. On three areas of reclaimed woodland which had been ploughed late, drilling conditions were not good.

Sugar beet, kale and grasses and clovers were all sown before the end of April. Potato planting started late, and the tilths, especially on late-ploughed land, were rather rough. Strong, cold winds during April dried the ground, retarded growth and delayed herbicide spraying.

Warm, sunny weather in May and June facilitated the cultivation of root crops, herbicide spraying and the making of hay and silage. All crops made good growth and looked promising.

July was mainly dull and wet, with many heavy falls of rain, and temperatures well below normal. Cereals ripened slowly and lodged extensively, but root crops grew well. The wet weather continued throughout August, when rain fell on 17 days; lodging

increased in cereal crops, and some of the lodged crops sprouted in the ear. Harvest started late, and was a slow, difficult operation spread over nearly 6 weeks. All the corn needed drying, as moisture contents varied between 20 and 24%, but though much of the grain was weathered, the yields were not much affected. The straw was brittle, and consequently of poor quality. Potato blight was very prevalent in July and August, and most of the haulms were burnt off at the end of August. Lifting started at the end of September.

The rainfall in October totalled 6·51 inches—3·55 inches above normal—and was spread over 28 days. This at first slowed down, and then completely stopped, potato lifting. Ploughing was delayed, and it became impossible to sow winter wheat or beans. The wet, cold weather continued until the end of the year. November's rainfall was 4·44 inches (1·65 inches above normal) spread over 28 days, and December's 3·65 inches (1·05 inches above normal) spread over 26 days. The land became completely waterlogged, and field work was impossible for long periods at a time. Sugar-beet harvesting was completed before the end of November, but the field was reduced to a slurry before carting was finished. Corn drilling and potato lifting were impossible, and at the end of the year most of the autumn work still remained to be done.

Field Experiments

The 1959–60 field experiments had an excellent start, and autumn-sown crops were drilled much earlier than usual. Favourable weather enabled the large spring programme to be completed, and all crops were sown in reasonable time. No crop failed, and damage by birds was slight. Despite the atrocious weather at harvest, all the cereal plots were harvested in reasonable condition, with less lodging than was expected.

Of the 10 potato experiments from which yields were required, six were lifted as usual with the elevator-digger. Conditions then prevented the further use of this machine, and on the other four experiments about a quarter of the area planned to be harvested by machine was lifted by hand. All dirt tares were higher than usual.

The sugar-beet plots were harvested under bad conditions, but the beet needed less cleaning than usual, as the water acted as a lubricant between the soil and roots.

Broadbalk, usually sown late to check the infestation of slender foxtail (*Alopecurus myosuroides*) and wild oats (*Avena ludoviciana*), was sown in perfect conditions in the middle of October 1959. 2 : 4-D ester was sprayed on the 1959 stubble of the permanent wheat section to control coltsfoot (*Tussilago farfara*), and this area was also sprayed in the spring with CMPP. These sprays gave good control of weeds, which were plentiful on the rest of the field and especially so on Section V, which also lodged worst.

Hoosfield permanent barley plots were sown late to check wild oats (*Avena fatua*). This policy of sowing late and hand pulling the wild oats is proving successful, and there were very few to pull this year. The spraying programme to control coltsfoot (*Tussilago farfara*) was continued as in 1959, except that, on strips 4, 6 and 7, CMPP was used instead of MCPA in spring because of the heavy

infestation of chickweed (*Stellaria media*) and cleavers (*Galium aparine*). Three plots (50, 5A and 4C) were sprayed with dalapon against twitch (*Agropyron repens*).

Barnfield, the classical mangold field, was fallowed in preparation for a new experiment in 1962, though dung and fertilisers were applied as for a crop. Small isolated areas of twitch (*Agropyron repens*) were controlled by spraying with dalapon and frequent rotary cultivations, though these were restricted by bad weather. Spraying with 2 : 4-D ester against creeping thistles (*Cirsium arvense*) was confined to affected areas.

On the Park Grass plots the modified forage harvester described in the 1959 Report was used to determine the yield of the first " hay " crop. Four cuts were taken from the wide plots and two from the narrow ones; the rest of each plot was cut with a mower and made into hay. This sampling method eliminates losses unavoidable in haymaking and considerably expedites the work. The same technique was used for the second cut, except that after the sample cuts had been made the rest of the grass was cleared by the forage harvester working in the normal manner. These methods of harvesting the Park Grass plots are now accepted as standard practice.

Moles were again active on some of the Park Grass plots, and poison bait was used against them.

Cropping

Of the 462 acres farmed, 276 were under arable crops or fallow, 124 under short-term leys or lucerne–grass mixtures and 62 were under permanent grass. The main arable crops were wheat (112 acres), barley (65 acres), oats (14 acres), beans (31 acres), potatoes (34 acres), and kale, sugar beet and swedes (9 acres). 11 acres were fallowed.

The cropping system is largely dictated by the requirements of experiments, but is based on a rotation of wheat, barley and either roots or beans. The acreage of potatoes is as large as can be handled, and enough kale is grown for the needs of the stock until Christmas. The sugar-beet area is kept small, because our land is unsuitable, and the balance of the root break is sown to beans, as this crop makes little demand on labour. Arable fields are rested periodically under grass or lucerne–grass leys, which are usually left down for 4 or more years, depending on the state of the sward.

This system is flexible and represents a compromise between the often conflicting demands of experiments on pests and diseases that require uninfected fertile sites and experiments on fertilisers that require sites likely to show a good response to nitrogen. Cropping is further complicated by restrictions on the use of phosphate and potash on some fields. Several such areas are now in " cold storage " under long-term leys or fallow.

Crops

Cereals

Except in experiments, Cappelle was the only variety of winter wheat grown. Jufy I replaced Koga II as the standard spring

variety because it yields more and stands better. Proctor remained the main variety of barley; Condor is now the standard oat variety.

The early sowing and mild winter favoured winter wheat. Spring corn had a good start; all cereals promised well at the end of June, and there was prospect of an early harvest. The weather soon changed this, for Cappelle in Highfield 4, 5 and 6, and some Proctor barley, became badly lodged. The lodged wheat grew in the ear, but as lodged crops were harvested when the straw was dry, losses were small.

The wheat averaged nearly 30 cwt./acre, barley 26 cwt./acre and oats 25 cwt./acre. The spring wheat was " Field Approved " and has been sold for seed.

All cereals were sprayed with herbicides with satisfactory results. CMPP, 2 : 4-D ester and TCB/MCPA were all used, the last more than usual, as it affects more of the weeds prevalent here.

Beans

The bean acreage was bigger than usual; some winter beans were damaged by birds and the crop was resown with spring beans. All spring and some winter crops were sprayed against weeds with " Simazine ". The effect in the dry spring was disappointing, and an inter-row cultivation was needed. A fairly heavy attack of bean aphis (*Aphis fabae*) on the spring beans was effectively controlled by one spraying with " Metasystox ". The crops continued to grow late in the season and were harvested in mid-September, though they were still soft. As usual, winter beans with a yield of about 34 cwt./acre, did better, except where damaged by birds, than the spring variety, which yielded about 23 cwt./acre.

Potatoes

The start of potato planting was delayed by about 2 weeks by the heavy programme of spring cereal experiments. With little frost, tilths were rather rough, especially on late-ploughed land, and some areas were rotary cultivated.

More King Edward VII and fewer Majestic were sown than previously; Ulster Supreme was used on three experiments. The crop was kept clean by inter-row cultivations, and earthed up by the end of June and sprayed before late blight (*Phytophthora infestans*) appeared in late July, but the disease spread quite rapidly, despite a second spraying. Most of the haulm was dying by the end of August, and was then burnt off with concentrated BOV.

The late corn harvest delayed the start of lifting until the end of September, after which conditions soon deteriorated. Yields were much higher than usual, 26 tons/acre from one experiment. The tubers were of good size and shape, almost free from common scab (*Actinomyces scabies*), even on areas where the disease is usually rife. Some of the tubers of the King Edward VII and Ulster Supreme but very few of the Majestic were blighted.

Sugar beet and kale

Both these crops were sown early in April and, after a rather slow start, grew well into the autumn. Beet, grown only on experi-

ments, were sprayed with "Metasystox" to check sugar-beet yellows, and yielded 22 tons/acre, with an average sugar content of 15·3%.

Weeds, especially fat hen (*Chenopodium album*) and creeping thistle (*Cirsium arvense*), grew vigorously in the kale. Inter-row cultivations were hampered by the rain, and on some areas lowered the yield. A new herbicide was tested against weeds in kale and controlled fat hen well enough to justify further tests.

Grassland

The grassland was chain-harrowed and given its first fertiliser at the end of February. Early growth was retarded by cold winds and lack of rain in April. In May recovery from early grazing was slow because of the dry weather, and by the end of June grass was quite scarce. Top dressings of nitrogen and the heavy rain in July made the grass grow rapidly and, as cattle were being sold regularly, it grew ahead of the stock. Extra cattle bought in September and October strip-grazed a field of long grass, much of which would have been wasted under free-range grazing. Before the end of November they had to be moved into yards because of the condition of the land.

Cutting for hay started before the end of May; this early cut was heavy and of excellent quality, but crops were light on those fields which had been used for early grazing. The grass was bruised by the forage harvester immediately after cutting, which expedited drying; in one spell of good weather hay was baled and carted within 24 hours of being cut. Most of the hay was of good quality, though some was spoilt because it was cut when weather forecasts were sadly wrong. During a rare spell of fine weather in September, 8 acres of grass were made into hay. After bruising, the crop was turned and tedded repeatedly for 4 days, when it was baled and carted just before rain fell.

Weather in late May and June was excellent for silage making, and a very heavy first cut of lucerne and cocksfoot was ensiled at the end of May; the second cut, taken in early July, was made half into hay and half into silage. A third, heavy cut was ensiled at the end of September, as was other surplus grass and the second cut from the Park Grass plots. More silage was made than ever before, and the cattle found it very palatable.

Livestock

Cattle

The policy of buying 18-month-old store cattle in the autumn and fattening them during the following summer and autumn was continued. In the dry summer of 1959 the cattle did not fatten well, and 40 were brought into covered yards in the late autumn for finishing. Sixty-one Hereford and Hereford-cross bullocks, bought in the autumn of 1959, were kept in open yards throughout the winter. They were fed entirely on home-produced bulky foods and maintained their condition well.

Grazing became scarce in June 1960, and some cattle were transferred to Woburn. There was ample keep throughout the late

summer and autumn, and the cattle thrived; altogether 100 cattle were sold fat, and all except the few retained for the Christmas Show went direct from grass. A further 83 dehorned Hereford-cross beasts were bought in the autumn of 1960. It was hoped that these would remain at grass until the end of the year, but the land poached so badly that they had to be brought into covered yards before the end of November. The yards, originally designed for 15 horned cattle, are now holding twice this number of dehorned beasts. They were fed on hay, straw, kale, sugar-beet tops and brock potatoes until towards the end of the year, when silage feeding started.

An organo-phosphorus insecticidal wash was used in the late winter of 1960 against warbles on store cattle; it worked fairly well on cattle with light coats, but less well on those with thick coats. The new store cattle were treated in autumn 1960, before they grew their winter coats.

Sheep

Flushing the ewes in 1959 on a lucerne–cocksfoot mixture was very successful. The ewes, all in their second breeding year, were in excellent condition at lambing, and most fed their lambs well. One hundred and thirty ewes put to the Suffolk ram produced 228 lambs, a percentage of 175. Several ewes suffered from prolapse of the uterus, and three Caesarian operations were done; all the ewes and most of the lambs survived, and only one ewe died during the lambing period. Rubber rings were used for tailing and castration.

The high lambing percentage gave more lambs than could be adequately fed at Rothamsted, or were needed for grazing plots in 1961. Consequently nearly 100 lambs were transferred to Woburn in September, and those sold fat were replaced by others. The remaining lambs at Rothamsted are being fattened as rapidly as possible to clear the farm of all sheep other than the breeding ewes. Two ewes were culled in autumn, and the 122 remaining were flushed on good grass.

Now that the Sheep Dipping Orders in Hertfordshire have been rescinded, a spray-race is used in place of the dip. All sheep were sprayed with a special preparation of dieldrin, about 10 days after shearing. They were run through the empty race twice for training, and the actual spraying caused little difficulty. They were sprayed again later in the season. This method of combating the sheep-maggot fly (*Lucilia sericata*), which saves much time, labour and loss of temper, seems as efficient as dipping.

Equipment

The storage capacity of the grain-drying and storage plant was increased by 80 tons by building five more galvanised-steel bins. The installation of a 10-ton bulk loading bin, complete with elevator, brought the storage capacity of the plant to 280 tons. A new high-capacity precleaner was installed.

A 70-inch rotary cultivator with a variable rotor speed, a tractor-mounted sprayer suitable for handling concentrated acid (BOV), and two tractors were bought.

Buildings and Roads

A timber-clad cattle shelter was built in Highfield.

The concrete apron around the farmstead was extended to serve all the implement sheds.

The racks and troughs of the two cedar-wood covered yards, designed for feeding hay and concentrated foods, were modified to facilitate the feeding of kale and silage from trailers, without entering the yards.

Estate Work

In addition to mechanical hedge-cutting and other routine estate maintenance, the work of clearing the old woodland areas of Claycroft, Longcroft and Appletree field, started in 1959, was completed. These areas were ploughed in late spring and sown to cereals; two of them produced satisfactory yields, but the crop on the third area was partially smothered by grassy weeds. The shelter belt of poplar trees parallel to the Redbourn Road was thinned, and the trees in Broadbalk Wilderness which overhung Broadbalk field were lopped.

Woburn

Woburn suffered less than Rothamsted from the unfavourable weather. The autumn of 1959 favoured the early sowing of winter wheat and beans, and field work was up to schedule at the beginning of 1960. Ploughing was delayed by the wet winter, but conditions were excellent in spring, and all cereals and beans were sown before the end of March. April was very dry, which favoured the drilling of sugar beet and kale and the planting of potatoes, but retarded germination and growth of most crops; the heavy land also cracked badly. Crops grew well in May and June, though the sugar beet germinated unevenly. A heavy storm in late June benefited the root crops but lodged some wheat and barley. Heavy rain in July delayed the ripening of cereals and increased lodging. Harvesting was delayed by rain throughout August and September, and potato blight (*Phytophthora infestans*) spread rapidly. All experimental potato crops were lifted before the end of September and sugar beet soon afterwards, but the harvesting of the non-experimental potatoes and sugar beet was interrupted by the wet autumn, and some sugar beet was still in the ground at the end of the year. Ploughing was delayed, and no crops had been drilled by the end of the year.

Cropping

Of the 127 acres farmed, 27 carried wheat, 25 barley, 9 beans, 19 potatoes and 6 sugar beet. There were small areas of kale, carrots, lucerne, rye and market-garden crops. Temporary grass occupied 22 acres and there were 4 acres of permanent grass.

Crops

Cereals

The winter wheat on all non-experimental fields was Cappelle and the spring wheat Jufy I. Herta barley was retained on the

long-term experiments, but Proctor was used on non-experimental areas. Drilled early and under good conditions, all crops grew well in late spring. The spring corn suffered from the dry weather in April, May and early June, and the crops were thin and the ears small. Fusarium disease appeared in spring wheat on a very light field, but the crop grew away from it in July. Cappelle wheat and Proctor barley after old grassland lodged severely, but elsewhere lodging was slight.

Winter wheat averaged 33 cwt./acre, but barley and spring wheat yields were disappointing, averaging only 20 cwt./acre.

Beans

The winter crop on heavy land was so badly damaged by birds that it was ploughed in. The spring crop, sown early, made good growth in the wet summer and yielded about 17 cwt./acre. An unusually heavy bean aphid (*Aphis fabae*) attack was controlled by one spraying with " Metasystox ". " Simazine " did not control weeds as well as in 1959, probably because the weather was dry after it was applied.

Potatoes

A small area was grown of the early varieties Arran Pilot and Ulster Chieftain. Majestic was the " main-crop " variety in most experiments, and Ulster Supreme replaced King Edward on most non-experimental fields, as King Edward has recently yielded poorly.

Planting was finished by the end of April. Both early and main crops made excellent growth during the summer. On the long-term Green Manuring Experiment Ulster Chieftain yielded 10·8 tons/acre, 2½ times the 1959 yield. Despite early spraying, late blight (*Phytophthora infestans*) soon appeared, and a second spray was given before the end of July. The disease spread rapidly during August, despite a third spraying, and by the end of the month the tops were dying. On small experimental areas the haulm was destroyed mechanically, but concentrated BOV was used on non-experimental crops. Almost every Majestic plant showed symptoms characteristic of primary leaf-roll, as did many other crops of this variety. Tubers were saved to be grown next year to see whether this resulted from an exceptional spread of the leaf-roll virus or some other cause.

The Ulster Supreme were manured generously, and yielded up to 24 tons/acre with an average of 21 tons/acre. Many tubers failed to pass through the 3¼-inch riddle fixed by the Potato Marketing Board, and many were blighted. Majestic and King Edward VII yielded less, but the tubers were of better size and fewer were blighted. Very few tubers had common scab (*Actinomyces scabies*).

Sugar beet

Irregular germination gave a rather uneven plant, but growth was rapid in the wet summer. A spray against aphids delayed the onset of sugar-beet yellows, but by September the disease was widespread. However, it came too late to have any serious effect on yield, and the crop continued to grow throughout the autumn.

At harvest the ground was so wet that nearly all the roots had to be hand-pulled and cleaned; small areas had even to be hand dug. The yield averaged 16 tons/acre of washed beet with a sugar content of 15·3%, giving an average sugar yield of 49 cwt./acre.

Market-garden crops

The leeks grew well during the mild winter, and the average yield, 7·25 tons/acre, was larger than usual. The early potatoes grew vigorously, and although their growing season was slightly shorter than in 1959, the yield was 9·1 tons/acre, 3·6 tons/acre more than in 1959. The red beet was rather uneven and gappy because germination was irregular and the average yield of 6·8 tons/acre is about 1 ton/acre lower than in the past two years.

Lucerne

A small experiment on lucerne was drilled in August, and germination was rapid. However weeds, mainly chickweed (*Stellaria media*) and Shepherd's purse (*Capsella bursa-pastoris*), grew even more rapidly; the weather prevented cultivations, and the crop was in danger of being smothered. The area was sprayed in mid-December with the desiccant " Diquat " when the lucerne was 4–5 inches high. The result seems satisfactory, as the weeds were killed and, although the tall lucerne stems were killed, the crowns appear to be undamaged.

Grassland

Given fertiliser early in March, the grass made good initial growth, but after grazing late growth was retarded by the dry weather. Grass was scarce in May and June, but from July onwards was plentiful.

The small area of hay was made, baled and carted without rain falling on it. The yield was good and the quality excellent.

Eight cuts were taken from the S.22 Italian ryegrass sown on the Irrigation experiment in October 1959, equalling the number taken from the old cocksfoot sward in 1959.

Livestock

Cattle and sheep

Fifteen Hereford-cross bullocks were bought in autumn 1959 and were outwintered. They were brought to Rothamsted in June and July to be finished and sold, and were replaced, when grass became plentiful in July, by 22 from Rothamsted. Most of these were sold at the end of September, and were not replaced because of the foot-and-mouth disease restrictions. The land was used to over-winter the store lambs needed for the grazing experiments at Rothamsted and Woburn. These 90 lambs were given sugar-beet tops and some fattened so readily that they were sold and were replaced by others from Rothamsted.

Pigs

Some of the older Large White sows were sold. The litter size and weight at weaning was low, and it is hoped to get better results in future. If so, the herd will be increased to its previous size of 20–25 sows. Most of the pigs were sold as pork.

The use of " Simazine " to control weeds in field beans and potatoes

Second Report

J. R. Moffatt and M. J. Hill

The results of four experiments in 1959 on the effect of " Simazine " as a pre-emergence weed-killer on beans and potatoes were given in the 1959 Report. A range of crops was grown on the same sites in 1960 to determine any residual effects. Two further experiments on the use of " Simazine " on potatoes and two on beans were done in 1960.

Residual effects of 1959 experiments

Cappelle winter wheat, Proctor barley, Condor oats, Thousandhead kale and Kleine E sugar beet, were grown in 1960 in strips across the 1959 plots at Rothamsted and Woburn. Observations were made throughout the growing season and yields were taken. There was no room for replication on individual experiments, and Table 1 gives the mean yields of all sites. Birds did some damage

TABLE 1

Rothamsted and Woburn

Test crops	Mean yields/acre over 4 experiments					
	O	S_1	S_2	S_3	A_2	Mean
Winter Wheat (1), cwt. (at 85% D.M.)	46·6	47·8	46·7	46·4	48·5	47·2
Spring Barley (1), cwt. (at 85% D.M.)	34·9	35·1	36·6	33·8	34·2	34·9
Spring Oats (1), cwt. (at 85% D.M.) ...	26·2	27·4	26·8	25·5	26·6	26·5
Kale (1), tons (total weight) ...	22·4	24·6	24·1	21·5	23·3	23·2
Sugar beet, tons (roots, washed) ...	17·2	18·7	15·6	17·1	16·3	17·0

Treatments applied 1959.

O = No weed control.
S_1 = Simazine. ½ lb. active material in 40 gallons/acre.
S_2 = Simazine. 1 lb. active material in 80 gallons/acre.
S_3 = Simazine. 1½ lb. active material in 120 gallons/acre.
A_2 = Atrazine. 1 lb. active material in 80 gallons/acre.
(1) = Mean of 3 experiments, the fourth was damaged by birds.

at Woburn, and damaged crops were not harvested for yield. No effects of the weed-killer were observed on germination or the subsequent growth of any of the crops. Yields of each crop were similar over all the experiments, except that on one, kale after the highest level of " Simazine " yielded 25% less than the control.

The yields of all crops except sugar beet were slightly higher where the two lower levels of " Simazine " had been given than

where weeds had been allowed to grow unchecked in 1959, and slightly lower where the highest level of the herbicide had been given. In three of the four experiments sugar beet yielded 1·6 tons/acre less on the S_2 plots than on plots where weed-killer was not given in 1959.

"Simazine" is not normally used at more than 1 lb./acre of active material, and these results suggest that this rate will not damage the following crop, even autumn-sown wheat.

Experiments on the use of "Simazine" in 1960

Tick beans were grown on heavy loam soil at Rothamsted and Woburn and were drilled 3–4 inches deep; Ulster Supreme potatoes were grown on heavy soil at Rothamsted and on a sandy loam at Woburn.

For beans a randomised block design with four-fold replication was used. The treatments were: no weed control; normal inter-row cultivation; "Simazine" at three levels (½ lb., 1 lb. and 1½ lb. active material/acre) without inter-row cultivation; "Simazine" at 1 lb./acre active material with inter-row cultivation. The herbicide was applied soon after drilling.

The potato experiments formed part of a rotation experiment and were in two randomised blocks. A cultivation treatment not introduced in 1960 gave replication of some treatments within blocks. The treatments were: no weed control; "Simazine" at ½ lb. and 1 lb. active material/acre applied immediately after planting with no inter-row cultivations; "Simazine" at 1 lb./acre as above with one final earthing up; early cultivations and "Simazine" at 1 lb./acre applied just before the crop emerged; normal cultivations without weed-killer.

Full agricultural details of these experiments are in Results of Field Experiments 1960.

Discussion

Weeds were counted and identified on four random sample areas of 180 sq. in. on all bean plots at the end of July. Tables 2 and 3 list the most prevalent weeds and the total annual weeds.

Tables 2 and 3 show that at neither farm did "Simazine" alone

TABLE 2

Tick beans—Rothamsted—mean weed numbers/sq. yd.

	O	S_1	S_2	S_3	N	S_2N
Chickweed (*Stellaria media*) ...	35·1	3·1	1·8	0·9	4·5	0·9
Cleavers (*Galium aparine*)	27·0	27·4	17·5	8·1	3·1	4·0
Black Bindweed (*Polygonum convolvulus*)	25·2	3·1	5·8	0·9	1·8	0·45
Orache (*Atriplex patula*)	18·0	29·7	9·9	11·7	0·4	0·9
Scarlet Pimpernel (*Anagallis arvensis*)	19·8	5·4	2·7	0·9	2·7	—
Slender Foxtail (*Alopecurus myosuroides*)	15·3	4·0	3·1	0·9	1·3	1·3
Knotgrass (*Polygonum aviculare*) ...	9·4	3·6	0·4	0·4	—	—
Speedwell (*Veronica* spp.)	5·4	—	0·4	—	0·9	—
Poppy (*Papaver* spp.)	4·9	—	—	—	—	—
Mayweed (*Matricaria inodora*) ...	5·4	—	—	—	0·9	—
Total annual weeds	181·8	78·3	43·2	24·3	17·1	7·6

control weeds satisfactorily, although the total annual weeds became fewer with each additional dose of herbicide. The dominant weeds at Rothamsted were cleavers (*Galium aparine*), black bindweed (*Polygonum convolvulus*) and orache (*Atriplex patula*), and at Woburn were black bindweed, orache and knotgrass (*Polygonum aviculare*). Mechanical cultivation controlled all these satisfactorily,

TABLE 3

Tick beans—Woburn—mean weed numbers/sq. yd.

	O	S_1	S_2	S_3	N	S_2N
Black Bindweed (*Polygonum convolvulus*)	65·4	50·4	6·6	2·4	6·0	—
Orache (*Atriplex patula*)	148·2	124·2	152·4	108·6	9·6	10·8
Knotgrass (*Polygonum aviculare*) ...	24·0	19·2	10·8	7·2	2·4	—
Chickweed (*Stellaria media*) ...	8·4	—	—	—	6·0	1·2
Redshank (*Polygonum persicaria*) ...	3·6	—	—	0·6	—	—
Mayweed (*Matricaria inodora*) ...	3·6	—	—	—	—	—
Total annual weeds	253·8	195·6	170·4	118·8	25·8	12·0

whereas "Simazine" controlled only bindweed satisfactorily. Where cleavers and orache were made fewer by the chemical the plants grew larger.

Individual plot yields show that the sites of both experiments were very uneven, probably from differences in pH, but this is under investigation. The irregularity ran across the blocks at Rothamsted and parallel to them at Woburn. The yield differences at Rothamsted (Table 4) are not significant. At Woburn, where the

TABLE 4

Tick beans—mean yield cwt./acre

	O	S_1	S_2	S_3	N	S_2N	Mean
Rothamsted:							
Mean (±2·0) ...	25·0	23·6	26·2	26·6	23·8	23·3	24·7
Increase (±2·9) ...	—	−1·4	+1·2	+1·6	−1·2	−1·7	—
Woburn:							
Mean (±0·9) ...	11·3	13·0	12·1	12·6	17·0	16·0	13·6
Increase (±1·3) ...	—	+1·7	+0·8	+1·3	+5·7	+4·7	—

O = No weed control.
S_1 = Simazine. ½ lb. active material in 40 gallons/acre.
S_2 = Simazine. 1 lb. active material in 40 gallons/acre.
S_3 = Simazine. 1½ lb. active material in 40 gallons/acre.
N = Normal inter-row cultivations.

effect of the uneven site was partly eliminated by the lay-out, the yields were considerably larger where weeds were controlled satisfactorily.

The mean yield of the worst block at Woburn was 9·5 cwt./acre and that of the best 21·3 cwt./acre. Table 5 gives the means of the

TABLE 5

Tick beans—mean yield cwt./acre

	O	S_1	S_2	S_3	N	S_2N
2 poorer blocks ...	6·8	8·8	8·2	8·6	13·9	12·3
2 better blocks ...	15·6	17·0	15·7	16·6	20·1	19·7

two poorer and the two better blocks separately and shows that weed competition had a proportionately greater effect on the poorer crop.

Weeds on the potato experiment at Rothamsted were counted and their dry weights determined by the Botany Department; with results shown in Table 6. At Woburn weeds were fewer and

TABLE 6

Potatoes—Rothamsted—mean dry weight and number of weeds/sq. yd.

	O	N	S_1	S_2	S_2E	S_2L
Dry weight, gm. ...	88·4	8·2	63·4	31·9	7·1	1·9
Number	98·0	15·0	58·5	31·5	9·0	5·0

were not counted. The percentage weight of greened tubers was measured at Rothamsted and the percentage weight of blighted tubers at Woburn (Table 7).

" Simazine " alone had less effect than normal inter-row cultivations on the weed population (Table 6). Weed control was satisfactory on N and S_2E treatments, but best on S_2L. The weeds were counted after the S_2E plots had been grubbed and earthed up, which explains why these had fewer weeds than the S_2 plots, though the two had similar yields.

TABLE 7

Potatoes—mean yield tons/acre

	O	N	S_1	S_2	S_2E	S_2L	Mean
Rothamsted:							
Yield (1)	8·7	14·2	9·9	11·9	11·8	12·1	11·6
% " greened " ...	8·2	16·2	13·6	13·8	10·9	6·6	12·5
Woburn: (2)							
Yield	21·6	24·2	19·6	21·0	22·4	19·2	21·4
% " blighted " ...	12·7	9·0	19·9	15·6	10·2	8·2	13·3

O = No weed control.
N = Normal inter-row cultivations.
S_1 = Simazine. ½ lb. active material in 40 gallons/acre.
S_2 = Simazine. 1 lb. active material in 40 gallons/acre.
S_2E = Final grubbing and earthing up only after Simazine applied early.
S_2L = Inter-row cultivations up to application of Simazine at emergence.
(1) = Treatments O, S_2E, S_2L ($\pm 0{\cdot}44$).
,, N, S_1, S_2 ($\pm 0{\cdot}31$).
(2) = Treatments O, S_2E, S_2L ($\pm 1{\cdot}51$).
,, N, S_1, S_2 ($\pm 1{\cdot}07$).

In both experiments, potatoes with normal cultivations yielded more than any of the " Simazine " treatments, even where " Simazine " was used with mechanical cultivations and weed control was good. The S_2L plots were darker green in late July and August, but this difference was not reflected in the yield.

A possible explanation for the high percentage of greened tubers on the plots which had a final earthing-up, N and S_2E, is that the soil loosened by this operation was later washed down by heavy rain. However, earthing-up decreased the percentage of diseased potatoes at Woburn.

In addition to the above experiments, " Simazine " was used on

early potatoes in an irrigation experiment at Woburn and on winter beans at both farms. Yields of potatoes were consistently less on the " Simazine "-treated plots, both with and without irrigation, and at two levels of nitrogen (Table 8). All plots had few weeds, which were not counted.

TABLE 8

Early potatoes—Woburn—mean yield tons/acre

	ON_1	CN_1	ON_2	CN_2	Mean
Normal cultivations ...	9·1	10·9	10·4	13·1	10·8
Simazine	7·1	8·4	8·6	10·7	8·7
Difference	−2·0	−2·5	−1·8	−2·4	−2·1

O = No irrigation.
C = 2·2 inches of irrigation.
N_1 = 0·6 cwt. N/acre.
N_2 = 1·2 cwt. N/acre.
" Simazine " was applied at 1 lb. active material in 40 gallons/acre.

Yields were not taken from one winter-bean experiment because of damage by birds or from one of the two blocks of the other because of damage by acidity. The treatments included " Simazine " at 1 lb. of active material/acre applied in the autumn and 1 lb. divided equally between autumn and spring. Both controlled weeds reasonably at Woburn, but the split application was much the better at Rothamsted.

" Simazine " was less effective in 1960 than in 1959, probably because of the dry spring. The rainfall in 1960 during the 4 weeks after the beans were sprayed was 1·10 inches at Rothamsted and 1·02 inches at Woburn, and after the potatoes were sprayed was 1·52 inches and 1·15 inches. Weeds were better controlled in the potatoes than in the beans. In 1959 the weed control was excellent in the Rothamsted beans, when 2·37 inches of rain fell in the 4 weeks after spraying, moderate in the Rothamsted potatoes and Woburn beans with 1·79 inches and 1·15 inches of rain respectively, and very poor in the Woburn potatoes with only 0·64 inches. The figures suggest that rain plays a critical part in determining the effectiveness of " Simazine ", which has a water solubility of only 5 p.p.m.

WOBURN EXPERIMENTAL STATION

C. A. Thorold

The total rain for the year was 33·14 inches, which has been exceeded only twice since 1880, in 1903 (34·45 inches) and in 1924 (33·52 inches). However, 1960 excelled these years in the number of rain-days (0·01 inches or more), of which there were 210, compared with 179 in 1903 and 176 in 1924.

In spite of the rain at harvest, field experiment plots were reaped satisfactorily. The pattern of excess rain shown in Table 1 for midsummer and autumn continued to the end of the year. Several of

Table 1

Monthly mean temperatures (means of maximum and minimum), total rainfall and daily means of bright sunshine for April to October 1960, with departures from long-period means in brackets

Month	Mean temperature (° F)	Rainfall (inches)	Bright sunshine (daily mean) (hours)
April	47·5 (+1·1)	0·40 (−1·53)	4·91 (0·00)
May	54·5 (+2·5)	1·19 (−1·01)	6·13 (+0·09)
June	60·1 (+2·6)	3·73 (+2·03)	8·69 (+2·08)
July	59·1 (−2·3)	3·15 (+0·71)	4·58 (−1·46)
August	58·9 (−1·8)	3·19 (+0·86)	4·90 (−0·96)
September	55·5 (−1·2)	3·51 (+1·48)	4·28 (−0·35)
October	50·4 (+0·9)	4·48 (+2·18)	2·07 (−1·32)

the experiment sites remained too wet to prepare seedbeds, and customary sowings of winter wheat and rye were not achieved. In this respect also, 1960 was exceptional, for even in 1903 and 1924 winter wheat was sown in November. However, yields in 1960 were affected less. In 1924 winter wheat gave one of the smallest yields since 1877, and in 1903 it was considerably below the average. The mean yield of wheat in certain plots of the " continuous wheat and barley " areas (Table 2) was 23·3 cwt./acre in 1959 and 22·6 cwt./acre in 1960, more than twice the mean for the period 1951–55 (9·3 cwt./acre).

Although the total rain for 1960 exceeded the long-period mean (24·78 inches) by more than 8 inches, there was a period in April, May and early June when there was rainfall deficiency. Table 4 shows that the first three cuts (10 and 31 May, and 22 June) of ryegrass benefited from an application of water equivalent to 3 inches of rain, but later the plots which had not been irrigated yielded more.

Field Experiments

Continuous wheat and barley

The strips of winter wheat and spring barley were drilled across the " continuous wheat and barley " areas, in the same positions as these two crops occupied in 1959. However, the total area of cereal cropping has been decreased by two new developments initiated by the Chemistry Department (*Rep. Rothamst. exp. Sta.* for 1959, pp. 39 and 54). Two strips of grass, each 30 links wide, have been planted across the wheat and barley areas, to check soil erosion. One is on the boundary between plots 1, 2, 3 and 4, 5, 6, the other between plots 4, 5, 6 and 7, 8, 9. To measure the residual effects of potash and phosphate fertilisers applied between 1876 and 1926, microplot experiments with potatoes and barley were started. These plots occupied the strip which would otherwise have been drilled with barley on plots 7, 8, 9, 11a, 11b.

The *Report* for 1959 (p. 184) considered the yields of wheat and barley for plots 1, 7 and 11b, in the " continuous wheat and barley " areas, in relation to mean yields between 1951 and 1955. Table 2 compares wheat and barley yields in 1959 with those in 1960; to do this it was necessary to provide new means, omitting areas which were not cropped in 1960.

Table 2

Mean yields of grain (cwt./acre) in plots 1, 7 and 11b of " continuous wheat " and " continuous barley " areas in 1959 and 1960

	Continuous wheat area		Continuous barley area	
	Wheat	Barley	Wheat	Barley
1959	20·5	23·2	26·1	22·5
1960	19·6	21·9	25·6	19·9

The table shows some decline in wheat and barley yields in both the " continuous wheat " and " continuous barley " areas. The unmanured plots 1, which are included in Table 2, were among the plots sampled by the Plant Pathology Department in July 1960, when take-all (*Ophiobolus graminis*) was found on wheat and barley straws. This disease is probably causing some of the loss in yield.

Six-course rotation experiment

This experiment ended in 1960; it started in 1930 on a part of Stackyard Field where a four-course rotation experiment ran from 1877 to 1910. There were temporary pastures in the period 1913–16, but arable crops were grown for over 10 years before the start of the six-course experiment. The full range of crops was not achieved in 1930, but all phases of the rotation were represented each year from 1931 onwards. Therefore, it is convenient now to consider the experiment as beginning in that year.

The rotation was sugar beet, barley, clover, wheat, potatoes, rye. These crops rotated on six areas, so that each crop of the rotation was present every year. The main object of the experiment was to provide information on the effects on yields of varying amounts of

the three standard fertilisers, nitrogen, potash and phosphate, in relation to the different weather of successive years. The arrangement of the plots was described and the results discussed up to 1948 in the *Rothamsted Report* for 1948, pp. 90–94. Consideration was then given to the possibility of detecting any soil exhaustion caused by using only mineral fertilisers, by examining the mean yield of each crop taken over successive periods of 6 years. Table 3 gives the mean yields of sugar beet, potatoes, wheat and barley for the first (1931–36) and the last (1955–60) of such periods, together with the means for the duration of the experiment (1931–60). It seems desirable for present purposes to exclude results for clover, because this crop failed in several years, including the last two. Rye results are omitted, because between 1931 and 1933 it was cut green and afterwards harvested when ripe.

TABLE 3

Mean yields per acre for two six-year periods (1931–36 and 1955–60) and for the duration of the six-course rotation experiment (1931–60)

	Sugar beet				Wheat		Barley	
	Roots (tons)	Tops (tons)	Total sugar (cwt.)	Potatoes (tons)	Grain (cwt.)	Straw (cwt.)	Grain (cwt.)	Straw (cwt.)
1931–1936	7·88	6·67	26·8	8·13	12·2	26·0	23·9	39·5
1955–1960	10·66	7·01	37·9	8·80	17·0	21·5	29·1	27·0
1931–1960	8·42	5·68	31·2	8·00	14·7	24·7	24·0	28·9

Table 3 indicates that, except for wheat and barley straw, yields were greater in the last six-year period (1955–60) than in the first (1931–36). Some of the improvement may reflect changes in the varieties grown; sugar beet has been Kleinwanzleben since 1943, when it replaced Kühn; Majestic potatoes replaced Ally in 1942; the winter wheat variety was Yeoman from 1931 to 1946 and from 1956 to 1960, Squareheads Master from 1947 to 1951 and from 1953 to 1955, and Red Standard in 1952. Plumage Archer has been the barley variety from 1930 to 1955, but from 1956 to 1960 the variety was Herta.

Crops have benefited in recent years from higher dressings of ammonium sulphate. The levels of nitrogen applications were doubled in 1956 for all crops except clover. This change was prompted by the high responses to nitrogen in this experiment. The responses to nitrogen, potash and phosphate, in relation to weather conditions, have been discussed by Yates and Patterson (*J. agric. Sci.* **1958, 50**, 102).

Green-manuring experiments

The experiment started in 1936 to observe the fertilising effects of various green manures, was changed in 1954 to compare the effects from ryegrass and from trefoil sown after early potatoes on barley; the effects from ryegrass and from trefoil undersown in the barley are tested in the succeeding crop of early potatoes. The mean yield of early potatoes on plots which have not had green manures was 10·3 tons/acre, compared with about 11 tons/acre after

trefoil and after ryegrass. An increase of ½ ton/acre is attributable to the residual effect of green manures from the old scheme.

Barley yields have been increased by green manures ploughed in either in autumn or spring; ploughing green manures in spring gave 3 cwt. extra grain/acre in 1960.

To avoid residual effects, and to extend the investigation of trefoil and ryegrass as green manures, new experiments were started. Unfortunately, the trefoil did not establish satisfactorily, apparently because nodulation failed (see p. 86). Trefoil similarly failed in the irrigation experiment.

Ley and arable rotations experiment

Lucerne plots in their 3rd year were so seriously infested with lucerne-stem eelworm (*Ditylenchus dipsaci*) as to constitute dangerous sources of infestation. Acting on the recommendations of the Nematology Department, the crop was not harvested, but destroyed and ploughed in. Parts of the plots were also fumigated with a soil sterilant.

Lucerne plots in their 2nd year were not seriously infested. The crop was cut three times (7 June, 28 July, 26 September), and then these plots were treated with an experimental nematicide.

Irrigation experiment

Italian ryegrass was established in the autumn of 1959, replacing Cocksfoot, which had deteriorated after 6 years cropping. The ryegrass was cut eight times, and Table 4 gives the mean yields.

TABLE 4

Mean weights of dry grass (cwt./acre) at each cutting, with and without irrigation

	Without irrigation	With irrigation
Date of cut:		
10 May	6·1	9·6
31 May	10·9	15·5
22 June	9·6	19·8
Total (3 cuts)	26·6	44·9
18 July	22·4	18·3
8 August	9·2	9·6
30 August	11·1	11·6
23 September	11·1	10·6
8 November	8·5	7·5
Total (5 cuts)	62·3	57·6

The ryegrass was first irrigated on 28 April; additional waterings in May and June brought the total given to an equivalent of about 3 inches rain, and these increased the yield of dry grass at the first three cuts from 27 to 45 cwt./acre. In the course of the subsequent five cuts, water (0·5 inch) was given only once in August; from July to November the unirrigated plots yielded 62 cwt./acre and the irrigated 58 cwt./acre.

In its 1st year the ryegrass has produced over 4 tons/acre of dry matter, compared with a mean yield of about 3 tons/acre from the preceding Cocksfoot sward.

Potatoes, which were grown from 1951 to 1956, replaced sugar beet in 1960. They were not grown from 1957 to 1959 because root eelworm (*Heterodera rostochiensis*) was present on all plots. After 3 years without potatoes, it was thought that early potatoes would escape serious eelworm damage, at least for one 3-year cycle. However, there was some yellowing shortly before harvesting, and many cysts were present on the roots.

Results from other trials with a triazine weed-killer, " Simazine ", suggested a particular use in the irrigation experiment (*Rep. Rothamst. exp. Sta.* for 1959, p. 179). Potatoes grown on low, rounded ridges, maintained by minimum cultivations, might use water more efficiently than in tall, pointed ridges maintained by normal cultivations, so " Simazine " was tested to see whether it would replace cultivations as a method of controlling weeds.

Table 5 shows that the yields of tubers lifted on 15 July were increased by irrigation, but, with or without irrigation, yields were greater on the plots that received " normal " cultivations than on those treated with " Simazine " at 2 lb. in 40 gallons/acre on 15 April, after planting on 7 April.

TABLE 5

Mean yields of early potatoes (tons/acre) grown with normal cultivations, and with minimum cultivations plus weed-killer (" Simazine ") application, with and without irrigation

	Normal cultivation	Minimum cultivation	Mean
Without irrigation ...	9·73	7·88	8·81
With irrigation ...	11·97	9·56	10·76
Mean	10·85	8·72	9·79

However, because of the dry weather after planting, few weeds developed on any of the plots, and conditions did not favour testing the efficacy of the weed-killer.

It was intended to establish trefoil on some plots after lifting the potatoes, to be ploughed in during the spring of 1961 before drilling a cereal crop. Unfortunately, the trefoil did not establish satisfactorily. On some plots it was adversely affected by residual toxicity from the " Simazine " applied in April 1960, but the failure was more general, apparently because of poor nodulation.

The mean yield of winter beans without irrigation was 22·6 cwt. grain/acre, and 34·4 cwt. grain/acre with irrigation equivalent to 3·3 inches rain given in May and June. Irrigation prolonged the period of growth; the unirrigated plots were combine-harvested on 10 August and the others on 26 August.

Market-garden experiment

Leeks harvested between 4 March and 26 April yielded 7 tons/acre, and the early potatoes also yielded well, at 9 tons/acre.

Globe beet was sown on 16 May, during the dry period which lasted until early June. Germination was irregular, and plant populations varied from plot to plot. Such differences commonly occur in this experiment, but the variability this year was greater than usual. The largest mean number of plants (thousands/acre)

was 133·1, and the smallest was 82·8. These differences were not consistently related to particular manurial treatments. The mean yield of "bulbs" was 6·85 tons acre, slightly less than the mean yield for the period 1954–59 (7·09 tons/acre).

Jerusalem artichoke

The *Report* for 1959 (p. 187) referred to an experiment in which the tops of some of the Topine and artichoke plants were cut in July, and the tops of the others in November. Early removal of tops greatly decreased the yield of tubers: the mean yield was 1 ton/acre compared with 7 tons/acre of tubers when the tops were left until November. This experiment is being repeated, to see whether early removal of tops affects yield of tubers differently in different years. In 1959, a dry year, the plants did not grow again after cutting in July. In 1960, a wet year, the tops grew well after cutting in July. (Mann and Barnes.)

DUNHOLME FIELD STATION

R. Hull

In October M. Glenister replaced E. W. Dunham, who left in August, and P. J. Last was appointed in November. The impending move of the Station to Suffolk has created difficulties in keeping and recruiting assistants.

S. N. Adams, R. A. Dunning and R. Hull contributed to the 23rd Congress of the International Institute of Sugar-Beet Research in Brussels in February. R. Hull also attended the meeting of the Virus Committee in Holland in January, and the Summer Congress in Vienna in June. R. A. Dunning gave a paper at the 11th International Congress of Entomology in Vienna. At the invitation of the Irish Agricultural Institute, R. Hull visited Eire in October to advise measures to control sugar-beet yellows.

The weather at Dunholme was representative of the main sugar-beet growing areas, extremely dry until the end of June and extremely wet afterwards. Only $3\frac{1}{2}$ inches of rain fell in the 4 months March–June. July–December produced 20·3 inches, with only 43 days without rain, of which only five were in October and November. Everywhere, corn and root harvest was delayed and difficult. Sugar beet was harvested from mud in December, and much remained in the ground at the end of the year. The spring and summer weather suited sugar beet, which covered the rows with foliage in June and grew vigorously throughout the autumn. The early drought affected the crop only on the poorest land. Yields of over 20 tons/acre were common, and the national average yield 17·38 tons/acre is considerably greater than in any previous year.

The British Sugar Corporation gave invaluable help with 100 field experiments in commercial sugar-beet root and seed crops and in mangold crops, as well as with regular surveys of diseases, aphids and other pests.

Broom's Barn Farm

Until C. J. Hingston was appointed Farm Bailiff in March, Mr. E. J. Cousins, agriculturist of the Bury St. Edmunds Sugar Factory, kindly organised the farming activities, and the British Sugar Corporation staff also helped with sowing and mechanically thinning the sugar beet. The first objective of the farming programme is to get the land into a satisfactory state for field experiments. By early April 140 acres were sown with barley, 23 acres with oats and clover, and 20 acres with sugar beet. All the cereals were freed from broad-leaved weeds with chemical weed-killers, but all crops were infested with wild oats, which grew densely in places. Two areas, amounting to about 35 acres, were infested with couch-grass and were treated with dalapon in the autumn. Corn harvest started at the end of July, but was not finished until 13 September, and the delay resulted in loss of much grain. The average yield was 1 ton/acre. An excellent stand of clover was established under the oats.

The sugar beet was grown with a minimum of hand labour. Lifting started on 12 October, but was continually delayed by the weather, and was not completed at the end of the year. The average yield was 13½ tons/acre, with an average sugar percentage of 15·5.

The Ministry of Agriculture Survey Section kindly surveyed the farm and fixed the sites for sockets to mark grid lines which divide the land into 5-chain squares. Surface soil samples from each 1-chain square, and sub-soil samples from each 5-chain square have been stored for reference purposes. Eleven acres (The Holt) were underdrained.

Contractors started the civil-engineering work in August, but work has been continually delayed by rain and mud. A 10-inch bore-hole, lined for 127 feet, has been sunk 282 feet into the chalk, and yielded water at 120–130 feet. The sewage line and works, roads and the irrigation main are being laid, and should be complete early in 1961. Plans for the buildings will be ready for tenders early in 1961.

Incidence of sugar-beet yellows

The fine autumn of 1959 and the mild winter resulted in large populations of *Myzus persicae* and *Aphis fabae* on spring hosts. The heavy infestations of aphids in 1959 had spread yellows virus widely by the end of the year, so in March the sugar-beet crop seemed to be threatened with an early attack of yellows. Green aphids started to infest sugar beet in mid-May, about the same time as last year, but developed slower, because of attack by predators and parasites which had built up on last year's aphid infestations. An average infestation of one green aphid per plant for the country's sugar beet was reached by 9 July, compared with 13 June last year, and then the infestation remained about the same or decreased. The black-aphid infestation paralleled the green, and never damaged the crop appreciably. Spray warnings were sent to growers by some sugar factories in the third week of May, and by mid-July most growers in the south and east had been advised to spray. Growers in some areas had spray warnings up to mid-July, and a few growers were advised to spray a second time. Of the total crop of 413,000 acres, 221,000 were sprayed, of which 51,000 acres had a second or third spray.

In September sprayed fields in the eastern counties were generally relatively green compared with the unsprayed ones, in which 80–100% of plants had yellows. In some areas spraying apparently failed to decrease yellows incidence satisfactorily, although it controlled the apterous aphids on the crop; the reason for this is not established, but it is possibly because winged aphids, many of which must have been infective, were active over a long period.

Yellows was more prevalent than usual in the south, west and north of England and in Scotland, but less prevalent than usual in East Anglia, where most crops were sprayed. For instance, at the end of September mean incidence of plants with yellows in sample fields in north Lincolnshire was 60%, and in Norfolk and Suffolk 20–27%—a reversal of the usual situation. Mean incidence in all sample fields at the end of August was 16·5%—about the same as the previous 2 years—resulting in a calculated loss of sugar yield of

about 7%. Before the crop was sprayed, about 50% of plants in the sample fields had yellows in years when the weather favoured spread of the disease, as it did in 1960. (Hull.)

Two field experiments with systemic insecticides checked the timing of the spray warning. A single application at the recommended time increased root yield by $2\frac{1}{2}$ tons/acre at Rothamsted, and at Broom's Barn.

At Rothamsted spraying 1 week before the recommended time increased root yield by 1 ton/acre; the local destruction of predators at the time of infestation by aphids did not affect the resulting aphid population. Predators, particularly Coccinellids, were exceptionally abundant, and they almost freed plants from aphids in mid-June. All plots were eventually recolonised by aphids. The incidence of yellows reached 60% in unsprayed plots.

At Broom's Barn a second application 2 weeks after the first was economically worth while. Unsprayed plots yielded 36·6 cwt./acre of sugar, those sprayed early 46·8 cwt., those sprayed late 49·3 cwt. and those sprayed on both occasions 52·3 cwt. The aphid population was larger than at Rothamsted, and eventually all plants had yellows. Predators invaded sprayed crops as soon as they were recolonised by aphids. (Heathcote.)

Sources of viruliferous aphids

Aphids were numerous on mangold foliage in the autumn of 1959 and in clamps in the spring of 1960. Spraying growing mangolds in the autumn with demeton-methyl killed most of the aphids, but did not ensure that the clamps were free from aphids in the spring. Fewer of the roots in the clamps made from sprayed mangolds had aphids than in the 21 corresponding clamps made from unsprayed mangolds, and the infestation was lighter. The method is not reliable enough, however, to recommend to growers. In these clamps the closer the mangolds were topped, the lighter was the aphid infestation in the spring.

In April and May aphid-infested mangold clamps were fumigated with methyl bromide in collaboration with Dr. Page and Dr. Lubatti of Imperial College Field Station. Preliminary laboratory trials at Imperial College showed that both *Myzus persicae* and *Rhopalosiphoninus staphyleae* are readily killed by low doses of methyl bromide, e.g., a CTP (concentration of gas in oz./1,000 cu. ft. × time in hours) of not more than 30, and that mangolds are not harmed by CTP's below about 200. Two clamps in the Lincoln area, and two in the Cambridge area, varying in size from 600 to 2,000 cu. ft., were fumigated under $\frac{10}{1000}$-inch polythene sheeting, and an 8,000-cu. ft. clamp near Cambridge was fumigated (under rubberised-canvas sheets with rolled joints) for periods of 2–17 hours with the quantity of methyl bromide adjusted to give an average CTP of about 100. All clamps were nearly freed from aphids by the fumigation.

Aphids were found in 44 of 101 samples of weeds from beet-growing areas examined between late March and early May. The weeds were of many species, but mainly *Stellaria media*, *Senecio vulgaris*, *Malva* spp. and *Plantago* spp. *Myzus ascalonicus* was recorded 22 times, *M. persicae* 10, *Macrosiphum* spp. 14, *Aulacorthum* spp. 9 and other species 6. None of the beet plants to which many

of these aphids were transferred developed severe yellows; a few developed a mild or transient yellowing.

This is the third year in which aphids found on field weeds in the spring have infected occasional sugar-beet test plants with mild yellows, but none with severe; in contrast, most aphids from mangold clamps, stecklings and beet debris give severe yellows. (Dunning.)

A few *M. persicae* and *M. euphorbiae* were found on the innermost leaves of wild beet at three sites on the Suffolk coast during March, and are presumed to have overwintered there. Coccinellids were common and kept the aphids under control, and virus spread from this source was not obvious. (Heathcote.)

Tolerant varieties

Varieties selected for ability to tolerate yellows were tested at Dunholme, Sprowston and Ipswich, in experiments which depended on natural incidence of yellows. At Sprowston, and in other experiments arranged in co-operation with the National Institute of Agricultural Botany and the Plant Breeding Institute at Cambridge and Walton-on-the-Naze, varieties were compared on demeton-methyl sprayed and unsprayed plots. This year the experimental varieties seldom exceeded or equalled the yield of commercial varieties, in contrast to the results in the dry year 1959, when yellows was early and aphids prevalent. At Sprowston the commercial varieties outyielded all except variety Bu. 6 on the sprayed plots and all except 59/6/3, Sh. 8A and Sh. 5 on the unsprayed plots, where yellows was prevalent but late. At Ipswich, yellows incidence varied from 20 to 70% in September on different varieties, but only 59/6/5 and 59/6/6 outyielded the commercial varieties.

At Dunholme, where yellows incidence was low but downy mildew prevalent, the commercial varieties equalled or exceeded the yield of the inbreds and out-pollinated varieties. All plants of some inbred lines (e.g., 59/4/3) had downy mildew, and some plants were killed by it, whereas other lines had few infected plants.

Varieties which resulted from interpollinating plants selected from hybrid varieties consistently outyielded Sharpes E and Bush E; the hybrids had been produced by crossing two tolerant lines. Yellows incidence was about 60% on the commercial and about half this on the more tolerant experimental varieties. Those with varieties 6 and 8 as the seed-bearing parents in the first hybrid exceeded the sugar yield of the commercial varieties by 11% and 10% respectively.

The growth of the tolerant hybrid Q1S/1 × A7S/1 (Q) was again compared with that of Sharpes E, both in the field and in the glasshouse. In the field, Sharpes E had more leaf area and retained it longer than Q and exceeded the sugar yield of Q by 10%. Yellows immediately decreased the leaf area of Sharpes E more than Q, and the difference persisted through much of the summer. With yellows, Q outyielded Sharpes by 45%. In the glasshouse Q produced a greater weight of leaf than Sharpes at first, but after 11 weeks Sharpes had more than Q whether infected or not. The effect of yellows on yield of dry matter in leaves, petioles and roots was apparent 27 days after infection (6 weeks after sowing). After 16½

weeks the percentage dry matter in the roots of Q, healthy and infected, was 20%; in Sharpes 22% and 19% respectively. Sharpes had more dry matter in the roots than Q when healthy, but when infected, Q outyielded Sharpes. When infected Q gave 80% of the yield when healthy, and infected Sharpes gave only 36% of its yield when healthy. (Hull.)

Insecticides

Five field trials tested various insecticides for control of aphids and yellows. At Cambridge all insecticides decreased aphid numbers on the 3rd day after spraying, but " Phosdrin " increased the number of apterous green aphids per plant on the 7th day, and both demeton-methyl and " Phosdrin " did so on the 14th day. On unsprayed plots 61% of plants had yellows by the end of August, but none of the insecticides decreased yellows incidence (infected-plant-weeks) significantly, and " Phosdrin " gave a significant increase at one count (10 August). On unsprayed plots at Spalding 34% of the plants had yellows at the end of August; spraying with malathion increased yellows incidence by 19%, and all other insecticides decreased it only slightly. At Peterborough all insecticides appreciably increased the low yellows incidence when applied once, but, when applied twice, phosphamidon and menazon gave decreases. At Dunholme all insecticides decreased aphid numbers on the 2nd and 6th days after spraying, but on the 19th day only demeton-methyl, dimethoate and menazon did so. Subsequent yellows incidence was relatively high (51% at end of August), and was decreased by all insecticides except fluoroacetamide; all increased yield. All insecticides decreased the low virus incidence at Waddington near Lincoln.

The average decrease in yellows incidence given by a single spray in all five trials was: demeton-methyl 23%, dimethoate 15%, fluoroacetamide 7%, menazon 21%. Phosphamidon was used in four trials and increased yellows incidence by 3% on average, compared with decreases of 11% by demeton-methyl, 2% by dimethoate, 10% by fluoroacetamide and 13·5% by menazon.

In the glasshouse, demeton-methyl and " Phosdrin " sprayed on to colonies of *Aphis fabae* on sugar beet gave 95% kill or better within 3 hours; dimethoate and fluoroacetamide within 22 hours; menazon took over 48 hours. When higher dosages of the same materials were watered over the soil surface, demeton-methyl and " Phosdrin " killed the aphids slower than when sprayed, menazon was slower initially but finally quicker, and dimethoate was quicker throughout. " Disyston " granules (average size 1·25 mm.), sprinkled on to the foliage and soil surface, killed some aphids rapidly, but took 48 hours to kill all; the same dose worked into the soil surface had no effect for 8 hours and took 72 hours to kill all. Persistence of the treatments was checked by reinfesting the plants with *A. fabae* 4 and 8 days after treatment. All the materials except " Phosdrin " were still active on both days.

Three field trials tested various combinations of " Disyston " seed treatments, broadcast or " in-the-row " soil applications and top-dressings to the foliage with granules, and demeton-methyl sprays. Seed dressing (1·6 oz. a.i./acre) and admixture of granules

(12·8 oz. a.i./acre) with seed decreased seedling emergence but not final plant numbers, and decreased yellows incidence. On average, a single spray with demeton methyl decreased yellows incidence (infected-plant-weeks) by 51%, and a single application of granular "Disyston" at 32 oz. a.i./acre, as a top dressing on the foliage after singling, decreased it by 62%. Two of the trials tested a second spray and a second top dressing which decreased yellows incidence by 62% and 82% respectively.

The relative phytotoxicity of two sizes of 5% "Disyston" granules (average 1·25 and 3·0 mm. diameter) and 5% phorate granules (0·75 mm.) were compared by drilling three rates of each material mixed with 8 lb. rubbed seed and also with 16 lb./acre of natural seed. The phorate and small-sized "Disyston" granules were more injurious than the large-sized "Disyston", giving more cotyledon tip-scorch, smaller seedlings and fewer plants. The plants recovered rapidly in June, and no treatment gave fangy roots at harvest.

In the steckling cover-crop experiment described below, part of each main plot was treated with demeton-methyl (standard spraying rate on 18 August, 23 September and 16 November) or with "Disyston" (April sowings—granules at 3 lb. a.i./acre top-dressed along the rows on 12 August after cover-crops harvested; July sowings—2·5% by weight of 50% seed dressing plus granules at 3 lb. a.i./acre worked into the seedbed on 22 July). During late summer and autumn of 1959, black and green aphids were fewest given "Disyston". In May 1960 numbers of apterous green aphids per plant were: control 12·7, "Disyston" 8·1 and demeton methyl 2·5. The yellows incidence in June was the same with both insecticides and only a little lower than on the control plots. (Dunning and Winder.)

Sugar-beet mosaic virus

Rigid particles, about 730 mμ long, were identified in the sap of beet plants with mosaic, confirming observations in Germany. Attempts to prepare an antiserum by injecting rabbits with concentrated preparations of mosaic virus failed. (Heathcote.)

Seed crops

Yellows was prevalent in seed crops in 1960. Occasional crops surveyed by the National Agricultural Advisory Service and British Sugar Corporation steckling inspectors in June had up to 50% of plants with yellows, and the average for 82 sugar-beet seed crops was 7·3%; mangold seed crops had up to 80% of infected plants with a mean of 18% for 52 crops. This relatively high incidence of yellows had not been detected in the steckling beds the previous autumn. In two-thirds of the sugar-beet seed crops the percentage of plants showing yellows increased more than 20 times between October and June, and 90% of mangold seed crops did so. The stecklings which were stunted by the drought of 1959 failed to show symptoms when infected, and possibly the disease spread later in the autumn and more extensively in the spring than usual.

The proportion of sugar-beet stecklings raised under cover-crops increased from 37% in 1951 to 88% of the 1,046 acres in 1960. At first only cereal cover-crops were used and the stecklings were sown

in April, but in 1960 37% of the cover-crop acreage was sown in July under mustard.

These crops call for different certification methods and present different disease-control problems than open beds or beds in spring-sown cover-crops; for instance, some are still covered with mustard 6 feet high in October, and downy mildew spreads in the stecklings during the winter and spring. This is a signal example of how changing agricultural practices present new research problems. Eleven sugar-beet steckling beds for the 1961 seed crop were destroyed because they had more than 1% of plants with yellows, and the average infection in the remaining 113 was 0·19%. Thirty beds of mangold stecklings had more than 1% yellows; average yellows incidence in the remaining 162 beds was 0·30%. (Byford and Dunham.)

Stecklings sown in April 1959 and others sown in July were grown-on *in situ* at Dunholme to produce seed in 1960. The table summarises the observations made on them:

Cover crop	Number of aphids/100 plants: Mean of several counts in autumn 1959		May 2–5 1960	% of plants with yellows		Seed yield
				3 Nov. 1959	13 June 1960	
	Black	Green	Green			lb./plot
April barley ...	5	10	30	—	23·5	34
April mustard	0	10	70	—	16·9	53
July mustard...	11	61	570	9·0	23·5	23
July linseed ...	7	27	1,190	4·5	21·6	33
July open bed	8	47	4,170	8·4	20·8	25

In the July sowings the cover-crops competed with the stecklings for moisture in the persistent drought, and the steckling population was decreased, especially by mustard. During the late summer and autumn aphids on the July-sown stecklings, especially under mustard cover, were more numerous than on the April sowings. The lowest virus incidence and highest seed yield followed April sowing under mustard cover. Transplanting in February from the April-sown mustard and barley cover plots and from the July-sown open bed decreased green aphids to one-tenth in early May. The effect of insecticides is reported in the work on insecticides. (Dunning and Winder.)

Seed treatment

As a result of good harvest weather, seed used in 1960 was of unusually high germination, was only lightly infected with *Pleospora betae* and few seedlings had black leg. For the first time in five seasons field trials in the 18 factory areas did not show ethyl mercury phosphate (EMP) steep to be a better seed treatment than a commercial organo-mercury dust fungicide. Both increased seedling stand by 17%. "Panogen", "Agrosol" and "Mist-O-Matic" fungicide increased stands by 5%, 9% and 7% respectively. Dieldrin dusted on to EMP-steeped seed gave slightly more seedlings per ounce of seed sown than EMP-steep alone; heptachlor dust, heptachlor liquid, γ-BHC dust and dieldrin mist gave slightly less,

and " Astex " significantly less. Commercial organo-mercury dusts containing γ-BHC or heptachlor gave slightly fewer seedlings per ounce than a dust containing fungicide only. The liquid combined-dressings " Ceresol " and " Mist-O-Matic " were only slightly inferior to the comparable fungicide, but " Panogen " + " Astex " gave 6% fewer seedlings than the untreated control.

In 1961 EMP-steep will be used commercially in Britain on all rubbed and graded, gravity-separated seed. (Byford and Dunning.)

In four field experiments near Lincoln " Agrosol " steep and " Agrosol " applied in a mixing drum gave seedling emergence comparable to that from EMP-steep, all giving 26% more seedlings than untreated seed; " Agrosol " applied as a spray gave only 19% more seedlings. " Agrosan " gave 20% more seedlings than untreated seed, and EMP applied as a spray in 6% or 1% volume/weight of water gave 20% and 21% more respectively.

In the field at Dunholme, both 1958 seed with high *Pleospora* infection and 1959 seed, when steeped in water before being treated with " Agrosan ", " Panogen " or " Agrosol ", gave fewer seedlings than seed that had not been steeped before treatment. Six further samples of seed with different amounts of *P. betae* infection gave a similar result with " Agrosol ".

Seed treated with " Agrosol ", " Panogen " or EMP at normal and higher doses had its germination greatly decreased after storage in polythene bags when the seed was moist, but not when stored in muslin bags; the inhibition zones produced on stemphylium–agar sheets were also much smaller. Both effects were much less pronounced with the relatively non-volatile dust dressing " Ceresan ". With EMP, the effect developed after only 2 weeks storage, and became more pronounced with increased moisture and mercury content. Treated seed dried before storage to its original moisture content germinated satisfactorily and gave inhibition zones of normal size.

Inhibition zone size in stemphylium–agar plate assays was affected by pH of the agar, by spore concentration and temperature of incubation, but not by depth of agar, or by sucrose content of the medium. (Byford.)

Two field trials at Dunholme on limestone and clayey loam tested the effects of excessive dosage of insecticide seed dressings on diploid (var. Sharpe's Klein E) and polyploid (vars. Sharpe's Polybeet and Hilleshog Polyploid) natural seed. Materials used were 30% γ-BHC and 40% heptachlor at normal (12 oz./cwt.) $2n$, $4n$ and $8n$ rates, and 40% dieldrin and 80% menazon at normal (9 oz./cwt.) $2n$, $4n$ and $8n$ rates. Leaf injury was detected in the polyploid varieties at the normal rate of γ-BHC, and was significant at $2n$ and above in all varieties, more so in the polyploid, especially Hilleshog, than in diploid varieties. Plant populations were decreased progressively by $2n$ and higher doses of γ-BHC, and loss of plants continued until the end of June. At harvest only γ-BHC at the $8n$ rate increased fanginess of roots. Pitting of the root at the original site of the seed was obvious at the $2n$ rate of γ-BHC and severe at higher rates, especially with Hilleshog Polyploid. Dieldrin, heptachlor and menazon, even at the $8n$ rate, produced no apparent injury throughout the season. (Dunning.)

Downy Mildew

Organo-tin fungicide sprayed on August-sown stecklings at 10-day intervals, starting immediately after brairding, decreased downy mildew incidence in early October from 23 to 2%. When sprayed at 30-day intervals 6·8% of plants had mildew. For "Dithane" sprays at 10- and 30-day intervals the percentage of infected plants was 6·8% and 16·7% respectively; for "Perenox", 13·2% and 12·2%.

After 7 days at 10° and 75% relative humidity, spores germinated when incubated in water at 10°, but not after 24 hours at 30°, and 100% or 90% R.H. (Byford.)

Herbicidal sprays

Various hormone weed-killers distorted and stunted sugar beet when sprayed on them at a tenth of the concentration used for spraying cereals. Sugar-beet sprayed at the end of May showed more severe symptoms than those sprayed at the beginning of May. Two-months-old sugar beet sprayed on 20 May with 2 : 4-D at a concentration of 1 : 20,000 showed typical severe injury for a week. After that the plants recovered and eventually looked greener and more vigorous than the unsprayed ones, although the leaves were narrow and their venation abnormal. In November the sprayed plots yielded only 1½% less weight of roots with 0·2% lower sugar content than the unsprayed. Hormone spray injury occurred in numerous sugar-beet fields as a result of drift from cereal spraying or from using contaminated machines for spraying sugar beet. In some fields the injury could not be explained in these ways, because it occurred in well-defined patches irregularly distributed in large fields. In each such field the previous cereal crop had been sprayed, and apparently the chemical had persisted in the soil. The distribution of the patches suggested excessive doses where spray machines had been cleared or refilled. (Dunham.)

Sugar-Beet Manuring

This report gives the more important results of a series of field trials conducted in co-operation with the field staff of the British Sugar Corporation in 1959; the results of the 1960 experiments are not yet known. A series of nitrogen top-dressing trials started in 1959 is being continued; most of the trials fell on unresponsive sites in 1959. The growth analysis of sugar beet receiving different levels of nitrogen fertiliser continued.

NPK–dung trials

Nine 3^3 factorial experiments tested 0·6, 1·2 and 1·8 cwt. N/acre as ammonium sulphate: 0, 0·5 and 1·0 cwt. P_2O_5/acre as superphosphate and 0·8, 1·6 and 2·4 cwt. K_2O/acre as muriate of potash both with and without dung.

Without dung, the most profitable average dressings were 0·6 cwt. N, 0·5 cwt. P_2O_5 and 2·4 cwt. K_2O/acre. Higher rates of nitrogen depressed sugar yield. The responses to potash were higher than in previous years. With dung, 0·6 cwt. N/acre was still the

most profitable dressing, but there was no gain from applying more than 0·8 cwt. K_2O/acre. A surprising result was that 1·0 cwt. P_2O_5/acre could be justified in the presence of dung. Dung gave a higher sugar yield than any combination of mineral fertiliser on heavy soils at Bury and Ipswich.

The average response to nitrogen was small. Although the summer drought may have affected response, the response was not high even on two irrigated fields.

NKSalt trials

In this series of experiments designed to measure the response curve of sugar beet to salt and the nitrogen–salt and potash–salt interactions, eight experiments tested all combinations of:

(*a*) 0·6 and 1·2 cwt. N/acre as ammonium sulphate;
(*b*) 0, 2 and 4 cwt. agricultural salt/acre;
(*c*) 0, 1·2 and 2·4 cwt. K_2O/acre as muriate of potash.

TABLE 1

The effect of salt on the response of sugar beet to nitrogen and potash. Mean of eight experiments in 1959

	Sugar yield (cwt./acre)				
	Cwt. N/acre		Cwt. K_2O/acre		
	0·6	1·2	0·0	1·2	2·4
Without salt	55·4	53·9	52·2	52·7	59·0
With 4 cwt. salt/acre ...	59·1	60·0	57·6	61·1	59·9

Table 1 shows that salt appreciably affects the response to nitrogen and potash. When no salt was applied, 0·6 cwt. N and 2·4 cwt. K_2O/acre were the most profitable dressings, as in the NPK dung series. By contrast, in the presence of 4 cwt. salt/acre, 1·2 cwt. N/acre could be justified, and there was no gain from exceeding 1·2 cwt. K_2O/acre. These results suggest that the NPK dung series is not a reliable guide to manuring in the presence of salt. For this reason, the NPK–dung trials were ended in 1960.

Ploughing-down of P and K trials

Ten experiments compared a spring application of 1·0 cwt. P_2O_5/acre as superphosphate and 1·5 cwt. K_2O/acre as muriate of potash, with the same fertiliser applied in the previous autumn and ploughed in.

Ploughing-down of P and K in the autumn is less effective than the spring application, lowering yield on average by 4·0 cwt./acre sugar. The results do not support the idea that ploughing-down might be effective in a dry summer, for even in 1959 ploughing-down was as inefficient as in the two previous wet summers. The spring fertilisers were applied on the rough ploughing, and the seedbed cultivations would mix them in the top few inches of soil. It seems that this makes the fertiliser available to beet even in a dry season.

In 1958 the spring application was thought to be better than the autumn, because at some sites plants on plots which received seedbed fertiliser made a quicker start. To investigate this possibility, a

starter treatment of 0·3 cwt. P_2O_5 + 0·5 cwt. K_2O/acre broadcast on the seedbed in addition to the other fertilisers was tested in 1959. With this starter dose, autumn- and spring-applied PK gave similar sugar yields.

These experiments have ended. In all 3 years fertiliser applied in spring gave a bigger yield than ploughed-down in the autumn, and there is no reason to advise farmers to change their current practice. (Adams.)

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

C. W. Montgomery and B. Plummer resigned to take up other positions and C. J. Folland and G. R. Suggett were appointed. R. S. Seale was seconded for survey work in Pakistan, but became ill and was replaced for most of the year by C. C. Rudeforth.

A. Muir visited Teheran for a Seminar on Soil Survey held by the Central Treaty Organisation. D. A. Osmond attended a meeting of the Correlation Committee for the F.A.O. Soil Map of Europe at Ghent and later visited Budapest to discuss the correlation of the legends of the soil maps of West and East Europe. R. A. Jarvis attended a course on the interpretation of aerial photographs at the International Training Centre for Aerial Survey at Delft, The Netherlands. B. W. Avery and D. Mackney attended the VIIth International Congress of Soil Science held at Madison, U.S.A., and participated in the excursions which provided opportunities to compare the chief soil groups with their British analogues and the methods used to maintain their productivity. A. Crompton spent three weeks in Russia visiting research institutes and examining soils comparable with some in England. G. D. Ashley visited the Netherlands in connection with the problem of the sea-flooded soils of the North Lincolnshire coast.

Several courses and numerous lectures were given and many field excursions were arranged; reports on soils and sites were prepared for several official bodies, and assistance was given to many students.

Soil maps and many diagrams and figures were drawn in the Cartographic Section for memoirs, and numerous drawings were prepared for various departments of Rothamsted Experimental Station.

Outbreaks of foot-and-mouth disease and the writing of memoirs interfered with the progress of the survey, but about 1,200 sq. miles were mapped, mainly on a reconnaissance basis.

Northumberland

Sheet 77, 7th series (Hexham)

The presence of glacial drift coming from the north-west into the western part of the sheet complicates the pattern of the distribution of the parent materials. This has necessitated detailed mapping of the series in parts of this district to determine the proportion of each and the distribution pattern. At the same time samples of the basal profile layers at 3 feet were taken at random in the Carboniferous drifts and the reaction determined to see if the drifts derived from the differing geological strata, e.g., Coal Measures, Millstone Grit, Scottish Calciferous Sandstone Series, differ significantly. As a

result, it is possible, for all practical purposes, to ignore this factor and to continue to divide the Carboniferous drift solely on a textural basis.

Close co-operation with the National Agricultural Advisory Service has been maintained, the most important way being the instruction in profile observation and description given to the Soil Chemistry Department and County Horticultural Officers in co-operation with the District Advisory Officers. (Ashley.)

Yorkshire

Sheet 71 (*Selby*)

The survey of this sheet at 1 : 63360 was continued with the mapping of 28 sq. miles, chiefly around Pocklington, Seaton Ross and Melbourne, of soils derived from post-Glacial sands and various calcareous drifts overlying lacustrine clay or Keuper Marl. The writing of the memoir on this and the adjacent Sheet 70 (Leeds) continues, and thin sections and mechanical analyses were made during a study of the pedology of soils derived from post-Glacial sands.

Investigations of the soils associated with the Chalk of the Yorkshire Wolds suggest that a substantial part of the soil material is derived from sources other than Chalk and is probably of wind-blown origin.

During a visit to the Soviet Union special attention was paid to the sod-podzolic soils and their relationship to sols lessivés, etc., and samples taken are being studied. (Crompton and Bullock.)

Lancashire

Detailed mapping of the Lowland mosses at 1 : 63360 is almost complete, and 80 sq. miles have been covered. The work is under the auspices of a Mossland Committee set up to investigate problems of management on these peaty soils. Following a request from the County Planning Department, reconnaissance mapping was concentrated around Knowsley and Hale where 140 sq. miles were mapped. The information is required in connection with future industrial development in this area.

At the request of the Ministry of Agriculture, Fisheries and Food the following projects were completed: (*a*) a detailed survey at the scale of 25 inches to 1 mile of the 22 acres of Fairfield Horticultural Experimental Station; (*b*) a similar detailed map at the same scale of the 150 acres of Fir Tree Farm, Scarisbrick; (*c*) an examination of the soils of all the trials on mossland made by the National Agricultural Advisory Service within the past 10 years; (*d*) an examination of profiles at Great House Experimental Husbandry Farm in connection with the sites of proposed lysimeter experiments.

The County Agricultural Committee requested a survey of Gift Hall Farm (120 acres), which was made in detail at the scale of 25 inches to 1 mile. (Hall.)

Derbyshire

Sheet 125 (Derby)

Outbreaks of foot-and-mouth disease stopped work early, but 26 sq. miles were mapped extending from the higher ground around Wirksworth to the lower coalfield south of Alfreton, where brown earths, gley soils and podzolized soils occur with minor areas of calcareous soils.

After the extraction of the ironstone near Corby, the overburden was left in a series of ridges ("hill and dale") and, at the request of the Ironstone Restoration Committee, visits were made to obtain details of soil formation on these sites of known history. Several differences were observed in the profiles of these immature soils which could be correlated with the aspect, age and vegetation of the sites. (Bridges.)

Shropshire

Sheet 166 (Church Stretton)

Although mapping is complete, further field work was needed to revise some units to be shown on the 1 : 63360 soil map and to sample profiles for laboratory and micromorphological analyses.

The fair copy of the map at 1 : 25,000 was completed and an extended legend prepared so that the map can be interpreted even without a memoir. The memoir is being written and will include information obtained in a survey of crop yields and farming practice.

Field investigation revealed a sequence of podzolized soils on granophyre, rhyolite and quartzite, under heath and old, coppiced, heathy oak-wood on the Ercall, comparable with that described from Sutton Park on sandstones and glacial sands. Soils on granophyre and rhyolite in different evolutionary stages occur together in complex relationships but the field occurrences suggest the development trend: sol brun acide–podzolised brown earth (podzol intergrade)–iron podzol–humus–iron podzol. The outcrop of quartzite coincides with well-developed humus–iron podzols with very thick A_2 horizons, especially on lower slopes, and marked humus and iron B horizons. Even on 30° slopes, the horizons are parallel to the surface, suggesting little oblique translocation of iron and humus. The ecological succession on these soils appears to be heather, bracken, bracken and birch.

Further work was done on soils developed on red marl with a view to correlating the ecological types in semi-natural woodland with properties of the underlying soil. Three distinct assemblages were found, largely controlled by the base status of the soil. (Mackney and Burnham.)

Cambridgeshire

Sheets 173 (Ely) and 174 (Thetford)

Mapping on a reconnaissance basis was continued around March, Littleport, Ely, Sutton and Southery, and about three-quarters of Sheet 173 (Ely) is now complete. No new series was recognised. The pale yellow mottlings in the fen clay were identified as minerals

of the jarosite group, and their occurrence appears to be associated with acid soil conditions (pH 4·0–5·0).

Following the preparation of a report and reconnaissance map of Sheet 174 (Thetford), work started in the spring with the aim of surveying all the Forestry Commission Plantations in the Thetford Forest, and about 37 sq. miles were mapped. The soil legend previously prepared was found satisfactory for detailed work, which has shown a relationship between the soils and the relief. Worlington and Santon series tend to occur on the raised plateau, whereas complexes containing Newmarket, Methwold and Worlington soils occur on the slopes.

Two new soils were found: a gravelly phase of the Worlington is common at the foot of slopes of the plateau and in dry valley bottoms, and deep, considerably gleyed sands containing layers of iron concretions were found at Wangford Warren and on the plateaux near High Lodge, south-east of Brandon. The water-table is evidently held up by an impermeable layer overlying the Chalk, for ground-water appeared at depths of 5–8 feet in pits in this soil, which will probably be mapped as a new series.

As mapping progresses the enumeration plots within the forest are being visited and the soils classified. Soil samples are being taken and pH measurements made, and it is hoped that soil differences may be correlated with tree growth. (Seale, Hodge and Corbett.)

Bedfordshire and Hertfordshire

Sheet 147, 7th series (Bedford and Luton)

The reconnaissance survey was continued, and about 230 sq. miles, largely in Hertfordshire, were completed. The following additional associations were mapped:

Charity—naturally acid brown earths on Head of plateau drift overlying Chalk and confined to the main Chiltern valleys west of the Mimran. Soils: Charity and St. Albans.

Oak—imperfectly drained soils found on boulder clay and occurring on the Chiltern plateau east of the Mimran and also on low-lying ground north of Hitchin. Soils: Oak, Hanslope and St. Albans.

St. Albans—naturally acid brown earths formed on glacial gravel in the Vale of St. Albans and to a lesser extent on the Chiltern plateau. Soils: St. Albans, Bengeo and Hatfield.

Bengeo—naturally acid brown earths on Head of glacial drift overlying Chalk or bedded gravels in the main Chiltern valleys east of the Mimran and in the Vale of St. Albans. Soils: Bengeo, St. Albans, Hatfield and also Charity where this group abuts on the Batcombe association.

Milton—a group of imperfectly to poorly drained soils on sandy drift over Chalk Marl and Gault in the Vale north of Hitchin. Soils: Milton and Landbeach. (King.)

Hertfordshire and Essex

Sheet 148, 7th series (*Saffron Walden*)

Approximately 290 sq. miles were mapped, the greater part being of the Hanslope association consisting mainly of Hanslope and Stretham series. The soils are heavy, calcareous and, for the most part, imperfectly drained. Other associations recognised are:

Oak—imperfectly drained, non-calcareous soils developed on boulder clay or local drifts derived mainly from boulder clay. The group occurs mainly on level or gently sloping sites and, around Felsted and Chelmsford, replaces the Hanslope as the dominant group on plateau sites.

Chelmer—medium-textured soils, mainly gleyed brown earths, found on valley sides east of the Stort where the geological succession normally is Chalky Boulder Clay overlying Glacial Gravels resting in turn on London Clay. The soils, developed on local drifts derived from boulder clay and gravel, are non-calcareous and coarse gravel or London Clay appears at depth.

Moulton—sandy, well-drained soils developed on very chalky gravel and Chalk rubble between Royston and Duxford. The soils are mainly calcareous on arable land, but under natural conditions a leached brown earth is often found.

Milton—soils associated with the late Pleistocene terraces of the Cam, Rhee and Granta, mainly of medium texture with occasional coarse, sandy patches. Ground-water occurs at variable depths, and the soils are usually slightly calcareous, except where the surface soil has a very coarse texture. (Thomasson.)

Glamorgan

One hundred and sixty sq. miles were surveyed on a reconnaissance basis, including the Gower Peninsula, the west Glamorgan coalfield up to the Swansea Valley and an extension of the region around Merthyr Tydfil which was started last year. A reconnaissance survey of 60 sq. miles in the vicinity of the Brecon Beacons was undertaken for the National Agricultural Advisory Service; this will also permit better correlation of certain soils in the Gower Peninsula and will eventually form part of the survey of Brecon County.

A survey, at 1 : 63360, of the 3,000-acre Pwll Peiran Experimental Farm, near Aberystwyth, was completed, and a report on the Forestry Commission Tair Onen Nursery, near Cowbridge, was prepared. (Crampton.)

Berkshire

Sheet 268 (*Reading*)

Mapping was continued at the 1 : 63360 scale, and 21 sq. miles were surveyed in the north-west quarter in the relatively high land west of the Thames between Streatley and Pangbourne. The physical conditions are similar to those in the Chilterns, and consist of an uplifted peneplain dissected by valleys cut into the Upper Chalk, the broad intervening ridges and plateaux bearing Pleisto-

cene drift formations, shown as "Clay-with-flints" or "Plateau Gravel" on the Geological drift map, together with outliers of the Reading Beds. (Jarvis.)

Gloucestershire and Wiltshire

Sheet 156, 7th series (Bristol)

The reconnaissance survey was retarded by laboratory work and the writing of the memoir to accompany the soil maps of Sheets 279 (Weston-super-Mare) and 280 (Wells), but 36 sq. miles were mapped around Tetbury. Three mapping units were employed, consisting of groups of soil series associated with the Great Oolite limestones, the Forest Marble clays and the Forest Marble sandy beds. In general terms the groups correspond with the Cotswold, Halstock and Sandhills groups recognised by K. L. Robinson in his survey of Dorset soils. Boundaries between the units do not coincide with obvious topographical discontinuities, so that their delineation depends entirely on soil features, and further progress with their mapping may therefore be slow.

A soil map of Fyfield Down Nature Reserve was prepared for the Nature Conservancy. The Reserve is interesting for the many sarsen stones found there. The soils are derived from Chalk, Coombe Rock and Clay-with-flints and, after ecological surveys are made, it may be possible to correlate the differing semi-natural swards with individual soils. (Findlay.)

Devon

Detained soil mapping was continued in the Nuffield Farm Project area of the Teign Valley. A further 20 sq. miles were covered, thus completing the field work apart from some necessary checking, correlation and sampling.

The soils encountered on granite, and Culm shales have been reported previously. In the south-east, shallow, acid loams and clay loams with free drainage were mapped on cherts and siliceous mudstones of the Lower Culm. Brown earths of similar character cover much of the zone of altered Lower Culm rocks fringing the granite. On the numerous diabase intrusions which diversify the Lower Culm the soils are shallow, brown loams with little horizon differentiation. Within the metamorphic aureole of the granite, the diabase is much harder and the soil has a more ochreous (B) horizon and a more silty texture.

The soils of the narrow strips of silty and clayey alluvium bordering the small streams are mainly ground-water gley soils. In contrast, the material forming the Teign flood-plain consists of granite-derived sandy loam overlying gravels and gleying is uncommon except at the foot of adjoining high ground.

Sussex

Sheet 332 (Bognor)

Attention was mainly confined to the Brickearth soils, and the survey was extended eastwards to the Arun, a further 30 sq. miles being mapped.

The underlying Pleistocene raised beaches rise inland in shallow steps which influence the topography even though covered by later Brickearth and Coombe deposits. At present three main beaches are recognised, the two lower being mainly covered by Brickearth, the upper one by Coombe deposits. The latter surface, the southern boundary of which is the old cliff line of the beach below, forms a narrow belt of gravelly soils between the Brickearth to the south and the Chalk Downs to the north. The cliff line is much wasted, and the angle is filled with a wash of Coombe deposits, the whole being masked by the overlying Brickearth. In spite of its subdued nature, it forms a significant rise between 50 and 75 feet O.D. parallel to and south of the Arundel–Chichester road.

The two lower surfaces are not readily distinguished from each other, the rise between them being only a few feet and the break having no direct effect on the drift geology, although its recognition is necessary to understand the soil pattern.

In the two higher terrains small streams have frequently cut through the Pleistocene drifts into the Tertiary clay, producing a narrow clay outcrop at the foot of the valley slopes. Because of their position, such outcrops are generally covered by a very variable colluvium from the soils above them. The colluvium over Tertiary clay is being mapped separately, but eventually much of it may be included in a complex with the narrow sub-parallel outcrop of the overlying raised beach sand. In the area underlain by the lowest and most southerly raised beach the streams cut into the underlying formation less often, but seawards a narrow outcrop of Tertiary rocks is sporadically exposed.

Alluvial soils proved to be more extensive than suggested by the area shown as deep alluvium on the Geological maps. Broad stretches of thin alluvium over Coombe Gravel occur south of Chichester and at Tangmere. The soils have dark-coloured, humose topsoils, and are sometimes calcareous, though more often the upper horizons are decalcified. The distribution of some of these soils and their relationship to streams suggest that they may indicate the sites of the spring-fed meres mentioned in a grant of land from the King of Wessex to Bishop Wilfred in A.D. 680. The alluvial area at Tangmere may represent the site of the tongued or forked lake which gave Tangmere its name.

A new gleyed soil developed on Brickearth was recorded near Climping. It is comparable with those of the Park Gate series, but contains much sand, probably aeolian, in the topsoil. The sand is clearly not related to the nearby recent sand-dunes, west of Littlehampton, and adjacent alluvium which pre-dates the dunes has comparatively little contamination in the surface. (Hodgson.)

Kent

Sheet 305 (*Folkestone*)

To complete the maps scattered areas were revised, and the memoir is now being written. The revision was combined with an investigation of the possible modifying effect of the larger soil fauna on the leaching of calcium carbonate from the soils. It was shown that ants often bring much calcareous soil to the surface from deep

levels in the subsoil and at the same time evidently assist in creating and maintaining macropores in the soil. Some problems of nomenclature and classification, possibly related to this activity, were also investigated, and many samples were analysed. (Green and P. Askew.)

Other Work

1. A comparison was made of brown calcareous soils overlying Chalk at the Bridgetts (Hants) and High Mowthorpe (Yorks) Experimental Husbandry Farms. The soils are morphologically similar and resemble those of the Andover series. Mechanical analysis and the sand mineralogy suggested that, although differing slightly in composition, the soils incorporate a high proportion of foreign silt and fine sand which are probably largely of aeolian (loessial) origin. (Avery, Crompton and I. Stephen.)

2. Reports on the soils of some forest nurseries were prepared for the Chemistry Department of Rothamsted Experimental Station. (Avery, Jarvis, Findlay, Crampton, Crompton and Ashley.)

3. A small-scale map of the soils of Yorkshire and a non-technical account were prepared for publication by the Yorkshire Grassland Society. (Crompton.)

4. Reports were supplied to the Agricultural Land Service in connection with a proposed sand and gravel working and the construction of farm buildings on peat. (Hall.)

5. Visits were paid to field experiments conducted by Dunholme Field Station and the National Agricultural Advisory Service. (Bridges.)

6. A site at Monk's Wood, Huntingdonshire, was surveyed at the request of the Nature Conservancy. (Hodge.)

Soils at more than 20 sugar-beet trials were examined in East Anglia for the Dunholme Field Station. (Hodge.)

7. Richmond Park, Surrey, was surveyed at the request of the Ministry of Works Advisory Committee for Forestry. (Jarvis.)

8. Assistance was given to the Soil Chemistry Department of the National Agricultural Advisory Service at Wye in selecting sites and farms for fertiliser experiments and surveys. (Hodgson.)

9. A soil map of potential horticultural areas on brickearth in West Sussex was supplied to and discussed with Dr. J. O'Connor of the Research Department of the Ministry of Agriculture, Fisheries and Food. (Hodgson.)

10. A detailed survey of The Nature Conservancy's Yarner Wood (400 acres) was completed. (Clayden.)

EFFECTS OF ULTRAVIOLET RADIATION ON PLANT VIRUSES AND ON THE CAPACITY OF HOST PLANTS TO SUPPORT THEIR MULTIPLICATION

By

A. Kleczkowski

That ultraviolet radiation (UV) can kill plant cells was first recognised by Maquenne & Demoussy in 1909, and that it inactivates a plant virus, namely tobacco mosaic virus, was first demonstrated independently by Mulvania and by Smith in 1926. The emphasis in early research was in comparing the rates of virus inactivation with the rates of killing bacteria, which it was hoped would shed light on the nature of viruses. Mulvania (1926) and Smith (1926) concluded that, as tobacco mosaic virus is much more resistant to UV than are bacteria, it is more comparable to an enzyme than to a bacterium. They compared their results with the virus directly with those obtained by other workers with bacteria, regardless of possible differences in intensities of irradiation or of the fact that the results were obtained in environments that differed widely in their capacities to absorb UV. No significance can, therefore, be attached to the comparisons. This was recognised by Duggar & Hollaender (1934a, b), who made comparisons by irradiating tobacco mosaic virus and different bacteria simultaneously in the same medium. They also found that the virus is much more resistant to UV than all the bacterial species that they tested. However, the considerable variation in susceptibility to UV between bacterial species and even between different stages of growth within one species (Zelle, 1955), and also between different plant viruses (Bawden & Kleczkowski, 1955), make a complete generalisation impossible.

The early trends in research on inactivation of plant viruses by UV very soon assumed the modern character when such problems as action spectra, kinetics, quantum yields, etc., were investigated. By contrast, research on the lethal effect of UV on plant cells progressed little and has not reached a quantitative stage. A new aspect of the subject was opened with the discovery of the phenomenon of photoreactivation, that is that some of the effects of UV on both plants and viruses can be reversed by visible light.

Action spectra

Tobacco mosaic virus is the only plant virus whose action spectrum for inactivation by UV has been determined, first by Duggar & Hollaender (1934a, b) and then slightly corrected (Hollaender & Duggar, 1936). The spectrum of the type strain of the virus is

rather unusual. Plotting relative efficiency of radiation against wavelength gave no peaks. The line rose steadily as the wavelength decreased from 290 mμ, slowly at first and then rapidly below 250 mμ. This has been confirmed recently by Siegel & Norman (1958) and by Rushizky, Knight & McLaren (1960). The action spectrum does not resemble the absorption spectrum of nucleic acid, of virus protein or of the whole virus. The action spectrum of the strain U2 differs from that of the type strain in that, instead of the rise below 250 mμ, it shows a slight drop; it thus has a peak in the vicinity of 260 mμ, and so slightly resembles the absorption spectrum of nucleic acid.

Preparations of the infective nucleic acid from tobacco mosaic virus behave very differently, for Rushizky *et al.* (1960) found that the quantum yields for the inactivation were independent of wavelength, both with and without photoreactivation, so that the action spectrum closely resembles the absorption spectrum of nucleic acid. They also found that reconstituted virus, i.e., the product of recombining separated nucleic acid and protein, behaves like the original virus.

Assuming that infectivity of the virus is a function of its nucleic acid component, the action spectrum of the nucleic acid is therefore drastically modified by the protein component either in the original or in reconstituted virus. This may be because the bonding between protein and nucleic acid protects the nucleic acid from damage by UV (Siegel, Wildman & Ginosa, 1956; McLaren & Takahashi, 1957; Bawden & Kleczkowski, 1959), and the degree of protection may depend on the wavelength. Some kinds of damage by UV in the protein may also interfere with initiation of infection, and such damage may occur predominantly within a particular range of wavelengths. The fact that the action spectrum of the U2 strain of tobacco mosaic virus deviates from that of the isolated nucleic acid less than does that of the type strain, and the fact that nucleic acid in strain U2 is much less protected from damage by UV than is nucleic acid in the " type " strain, suggests that the protection may contribute to the deviation of the action spectrum of the whole virus from that of the isolated nucleic acid.

Kinetics of inactivation

Gowen & Price (1937) and Lea & Smith (1940) concluded that inactivation by UV of tobacco mosaic virus, tomato bushy stunt virus and a tobacco necrosis virus proceeds according to the first-order kinetics, i.e., plotting logarithms of proportions of residual infectivity against doses of irradiation gives straight lines. These authors assumed that residual infectivity over wide ranges is exactly proportional to the numbers of lesions produced on leaves inoculated with irradiated preparations, which is not true in general. Nevertheless, Oster & McLaren (1950), who computed the extent of inactivation by finding dilutions at which irradiated and control solutions of tobacco mosaic virus gave equal numbers of lesions, and Bawden & Kleczkowski (1953), who obtained residual infectivities of irradiated preparations of tobacco mosaic virus, tomato bushy stunt virus and a tobacco necrosis virus, by interpolation from dilution curves obtained by inoculating control virus preparations over a

range of dilutions, also found that inactivation proceeds, approximately at least, according to the first-order kinetics.

Because of the first-order kinetics, most workers concluded that virus particles are inactivated by " single hits ", i.e., by single quanta of radiation energy that happen to " hit " regions essential for infectivity. That this may, but need not, be so was pointed out and discussed by Kleczkowski (1960). One fact that throws doubt on the " single-hit " hypothesis, without, however, disproving it, is the extreme smallness of quantum yields. For example, a particle of tobacco mosaic virus absorbs on the average about 25,000 quanta of the radiation of 254 mμ before it is inactivated (Oster & McLaren, 1950; Kleczkowski, 1954).

Photoreactivation

The phenomenon called photoreactivation was discovered by Kelner in 1949, when he found that the proportion of *Streptomyces griseus* conidia that survived UV irradiation was greater when they were subsequently exposed to visible light than when kept in darkness. That the phenomenon extends to some plant viruses, and to leaf cells of such plants as French bean, was found by Bawden & Kleczkowski (1952, 1953). Irradiated viruses do not have their infectivity increased by exposure to visible light *in vitro*. The phenomenon operates through some light-sensitive mechanism in the host cell and shows by the proportion of surviving infective virus being greater when plants are exposed to daylight after inoculation than when they are kept in darkness. Keeping the plants in light or darkness for a period of time before inoculating them with UV-irradiated virus does not affect the apparent proportions of surviving infectivity of the virus.

Whether exposure to visible light reverses the damage caused by UV to plant viruses and to leaf cells, or counteracts the damage in some other way, has yet to be established. However, Lennox, Luria & Benzer (1954), by studying the rates of repeated inactivation and photoreactivation of a bacteriophage inside its host cell, showed that the change caused by UV in the bacteriophages is probably reversed by photoreactivation, and this conclusion probably applies generally.

Photoreactivation increases the residual infectivity of UV-irradiated virus preparations, but does not restore it to its original level. Hence the radiation causes two kinds of damage, only one of which is photoreversible. Kleczkowski (1960) gave evidence that the reversible and irreversible damage occur independently and that the irreversible damage is not a further change in particles already changed reversibly.

The inactivation of plant viruses by UV apparently proceeds according to the first-order kinetics, whether or not photoreactivation operates. Thus, if v is the dose of irradiation, the proportion of residual infectivity with photoreactivation is $p_{\text{light}} = \exp(-k_{\text{light}}v)$ and without photoreactivation $p_{\text{dark}} = \exp(-k_{\text{dark}}v)$, where k_{light} and k_{dark} are constants characteristic for a given virus in a given set of conditions. A ratio $k_{\text{light}}/k_{\text{dark}}$ equal to one means there is no photoreactivation, and any excess of the ratio over one shows the extent of photoreactivation. The ratio differs considerably with

different viruses (Bawden & Kleczkowski, 1955). It may possibly differ even with one virus, depending perhaps on the species of host plant in which photoreactivation is obtained, or on the condition of the host plant, but this has yet to be investigated.

Of several plant viruses now tested, all have shown the phenomenon of photoreactivation except tobacco mosaic and tobacco rattle viruses. Although these two are not photoreactivated when irradiated intact, photoreactivation is shown when their freed nucleic acids are irradiated. (Bawden & Kleczkowski, 1959; Harrison & Nixon, 1959.)

A fact immediately obvious from comparing the rates at which intact tobacco mosaic virus and its free nucleic acid are inactivated by UV is that the nucleic acid is much more resistant to inactivation when it is a part of intact virus than when free (Siegel, Wildman & Ginosa, 1956; McLaren & Takahashi, 1957; Bawden & Kleczkowski, 1959). When the isolated nucleic acid is irradiated, about half of the absorbed radiation energy seems to be concerned with the kind of damage that is reversible by photoreactivation and the other half with the irreversible damage. When intact virus is irradiated, inactivation by radiation energy absorbed per unit of nucleic acid progresses at a rate that is roughly only about one-tenth of that of free nucleic acid, and no photoreactivable damage occurs (Bawden & Kleczkowski, 1959).

The probable reason for the nucleic acid being more resistant to UV when inside the virus than when free is that the type of bonding between the nucleic acid and the protein reinforces the structure of components of nucleic acid. The degree to which nucleic acid is protected by the protein differs with different viruses, and even with different strains of the same virus, as for example with strains U1 and U2 of tobacco mosaic virus (Siegel, Wildman & Ginoza, 1956). Results obtained by Kassanis (1960) suggest that the nucleic acid of a tobacco necrosis virus may be protected only very little or not at all by the protein component. These differences can be explained by assuming differences in the nature of bonding between protein and nucleic acid.

The lack of photoreactivation with tobacco mosaic virus when irradiated intact could have two explanations. The bonding with protein may protect the nucleic acid from the photoreversible kind of damage, while allowing the irreversible kind, or it may prevent visible light from reversing changes caused by UV radiation. That the first is the correct explanation was shown by the failure to obtain photoreactivation when plants were inoculated with the nucleic acid isolated from virus irradiated while intact (Bawden & Kleczkowski, 1959).

Of the plant viruses yet tested, potato virus X showed the phenomenon of photoreactivation most strongly, and using this virus, photoreactivation could be roughly timed. With tobacco plants inoculated with UV-irradiated potato virus X and kept at about 20°, it mattered little whether they were in light or in darkness during the first 30 minutes. After that period had passed, most photoreactivable virus was photoreactivated during about 15 minutes in ordinary daylight, but only when the plants were exposed to light during the next hour. Thus the condition of the virus particles

that are reversibly inactivated by UV changes twice in inoculated leaves. The first change makes them ready for photoreactivation, and, if photoreactivation does not then occur soon, the second change makes them inactive irreversibly (Bawden & Kleczkowski, 1955).

The irradiated free nucleic acid from tobacco mosaic virus behaves differently. Most reversibly inactivated nucleic acid seems to become photoreactivable either immediately or within a few minutes after inoculation to the host plant (*Nicotiana glutinosa*); if it is not photoreactivated within an hour or so, most of it becomes irreversibly inactive (Bawden & Kleczkowski, 1960).

The lethal effect of UV on cells of higher plants can also be reversed by photoreactivation (Bawden & Kleczkowski, 1952; Tanada & Hendricks, 1953; Benda, 1955; Chessin, 1958), but there is no information about the rate at which cells are killed by UV radiation, the extent to which this can be reversed by photoreactivation, the rate of photoreactivation and the effect of time-interval between exposure to UV and to visible light.

Action spectra for photoreactivation of UV-effects on infectivity of plant viruses or on viability of plant cells have not yet been obtained. However, by the use of selective light filters Tanada & Hendricks (1953) found that the lethal effect of UV on cells of leaves of soybean was prevented by light of wavelengths shorter than 450 mμ, and Chessin (1958) found the same with French bean leaves and also with potato virus X. These results fit with those previously obtained with other materials, such as a bacteriophage (Dulbecco, 1950), *Escherichia coli* and *Streptomyces griseus* (Kelner, 1951). The action spectra for photoreactivation of these materials have peaks near 350 or 450 mμ and fall to zero below 300 and above 500 mμ.

Loss of infectivity and structural alteration in virus

The photochemistry of inactivation of plant viruses by UV is still unexplored. All the information shows that irradiation destroys infectivity without causing any gross changes in the structure of the particle. That virus preparations could be inactivated but still retain their ability to crystallise and to react with specific antisera has long been known (Stanley, 1936; Bawden & Pirie, 1938a, b). Oster & McLaren (1950) found that tobacco mosaic virus preparations that had lost more than 98% of their infectivity showed no change in viscosity, sedimentation constant, optical turbidity, isoelectric point, appearance in the electron microscope or UV absorption spectrum. McLaren & Takahashi (1957) also found that infective nucleic acid isolated from tobacco mosaic virus did not alter appreciably either in viscosity or in UV absorption spectrum after it had lost 99·99% of infectivity. All this suggests that neither the protein nor the nucleic acid components are much altered when infectivity is lost.

The structural changes responsible for loss of infectivity are unknown, but as pyrimidines are very much more susceptible than purines to changes by UV, it is reasonable to suspect that loss of infectivity results from damage in pyrimidine residues of the virus nucleic acid. Whether the photoreversible change caused by UV in virus nucleic acid is the reversible hydrolysis in the double bond between 5 and 6 positions in cytosine and uracil, as suggested by

Shugar & Wierzchowski (1958), is still questionable, for it has so far been reversed only by acid, alkali or heat, and whether in suitable conditions it can also be reversed by exposure to visible light still remains to be tested.

Inactivation of the capacity of plants to support virus multiplication

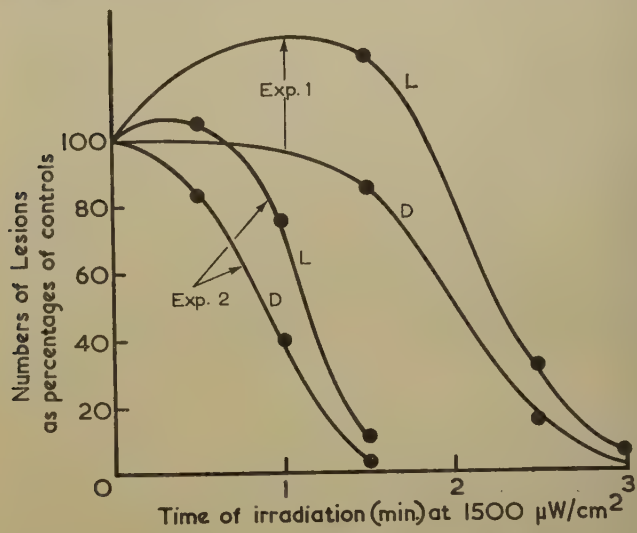
The word " capacity " is used here to mean the ability of a leaf to support multiplication of a virus to the extent of forming local lesions. The only current method of measuring the effect on capacity of exposing a leaf to UV radiation is to observe the effect on numbers of lesions formed by virus preparations that are inoculated to the leaf after it has been irradiated (Bawden & Kleczkowski, 1952, 1960; Benda, 1955; Bawden & Sinha, 1961). Hence there is no way of differentiating between the possibilities that irradiation affects capacity by influencing only the initiation of infection, only some later stage in the process or both.

The relationship between the lethal effect of UV on plant cells and on their ability to support virus multiplication is uncertain. A cell that has already died and collapsed is obviously unable to support virus multiplication, but it is possible that virus could multiply in a cell that has received a lethal dose of radiation and spread from it to neighbouring cells before the initially infected cell dies and collapses, and that a cell not lethally injured could have its ability to support virus multiplication destroyed.

The effect of a given dose of UV radiation on the capacity of leaves differs greatly, not only between different species of plants but also between individual plants of the same species, in which it depends very much on the age of plants, the season, the conditions under which they have been grown and on the temperature or quantity of illumination to which they have been exposed for some time before irradiation (Bawden & Kleczkowski, 1960; Bawden & Sinha, 1961). Consequently the relationship between the amount of irradiation and the effect on capacity of a given leaf to support a given virus is an individual property, and can no more be expressed in generally applicable terms than can the relationship between virus concentration in the inoculum and the number of lesions it will produce. The conditions so far known to increase susceptibility of capacity to UV also increase susceptibility to virus infection, but whether the connection is more than fortuitous has yet to be established.

The total effect of UV radiation on capacity can be determined only by putting leaves in darkness after they are irradiated, for exposure to daylight counteracts the damage (photoreactivation) (Bawden & Kleczkowski, 1952, 1960; Benda, 1955; Bawden & Sinha, 1961). The figure shows the results of two experiments in which *Nicotiana glutinosa* leaves were exposed to different doses of UV radiation immediately before they were inoculated with tobacco mosaic virus, after which half of the leaves were kept for 24 hours in darkness and half were exposed to daylight. The much greater susceptibility to UV of the leaves used in Experiment 2 is obvious, but the effect of photoreactivation is more spectacular in Experiment 1. In both experiments the numbers of lesions formed after photoreactivation depended on the dose of UV irradiation. With

small doses, photoreactivation increased the numbers above that of the non-irradiated controls; with intermediate doses, it restored them to the levels of the controls; with larger doses it increased the numbers but did not restore them to the levels of the controls. The effects of irradiation are obviously complex. Some are reversed by photoreactivation, and some are not. The increase in numbers of lesions above the original level when leaves were exposed to daylight after exposure to small doses of UV radiation may mean that the radiation can increase the leaf's capacity directly, or that photoreactivation can over-compensate the radiation damage and thereby



The figure shows results of two experiments in which halves of leaves of *Nicotiana glutinosa* were irradiated at λ 254 mμ and then the whole leaves were inoculated with a solution of purified tobacco mosaic virus; L = leaves in daylight after inoculation; D = leaves in darkness for 24 hours after inoculation.

make conditions in some cells such that infection can now occur, although it would not had the cells remained in their original state.

The time required for photoreactivation to be completed after leaves have been given different doses of UV radiation has not been studied in detail, but with moderate doses it probably happens in a few hours in ordinary daylight. The results of inoculating leaves immediately after they have been irradiated differ with different viruses and with different types of inocula. The figure shows that with tobacco mosaic virus considerably more infections are obtained when irradiated leaves are exposed to daylight than when kept in darkness. However, this does not happen with inoculum of free nucleic acid from tobacco mosaic virus, with which no more, or only very slightly more, lesions are obtained on UV-irradiated leaves

exposed to daylight than on those kept in darkness (Bawden & Kleczkowski, 1960). When the irradiated leaves are exposed to daylight for 3 hours before they are inoculated the nucleic acid behaves like the intact virus, and the numbers of lesions formed by the two types of inoculum are equally increased by exposure to daylight. It seems that, whereas the nucleic acid cannot survive infective in irradiated cells until their capacity is restored by photoreactivation, intact particles of the virus can. Different viruses differ in their ability to survive in irradiated cells undergoing photoreactivation. The Rothamsted tobacco necrosis virus inoculated to irradiated French bean leaves behaves similarly to the nucleic acid from tobacco mosaic virus (Bawden & Kleczkowski, 1952), whereas red clover mottle virus is intermediate in its behaviour between tobacco mosaic virus and the tobacco necrosis virus (Bawden & Sinha, 1961). The nucleic acid of this virus also seems more stable *in vivo* than that of tobacco mosaic virus, for when inoculated to leaves immediately after they are irradiated it gives more lesions on leaves kept in the light than in the dark, though the effect of the light is smaller than with inocula of intact virus particles.

Irradiating virus-infected leaves

Arthur & Newell (1929) found that tobacco mosaic virus " could be killed with a short exposure (to UV-radiation) when spread upon the plant leaf surface if irradiated at once. If irradiated the day following inoculation there was no appreciable killing of the virus. It is apparently impossible to inactivate the virus when it has penetrated far into plant tissue, although irradiations were given of sufficient intensity and quality to kill the whole upper surface of plant leaves ".

The subject of the effect on viruses of irradiating virus-infected plants remained (to the reviewer's knowledge) untouched for 25 years, until the results of irradiation studies with bacteria infected with bacteriophages (Luria & Latarjet, 1947; Benzer, 1952; Benzer & Jacob, 1953) stimulated further work (Bawden & Harrison, 1955; Siegel & Wildman, 1956). Unfortunately some concepts brought across from the work with bacteriophage were inapplicable to infected leaves and have led to conclusions that further work has shown to be unjustified. The effect of irradiation has been assessed by comparing the numbers of lesions that develop on irradiated halves of leaves with those that develop on unirradiated halves. Differences were attributed solely to the inactivating effect of radiation on virus particles, whereas what was measured was the effect on what can be called " infective centres ", and their exact nature is unknown. They may be virus-infected cells or groups of cells, virus particles that are about to infect or cells that are about to be infected. Thus, destroying an infective centre may mean inactivating virus, or affecting cells or virus-cell association.

Effects of irradiating leaves at different times after inoculation on numbers of lesions not only confirmed Arthur & Newell's (1929) conclusion that virus soon spreads from epidermis into deeper tissue where it is protected from the radiation but has also established some other phenomena. Thus, with a tobacco necrosis virus in French bean leaves (Bawden & Harrison, 1955), and with tobacco mosaic

virus in leaves of *Nicotiana glutinosa* (Siegel & Wildman, 1956), the resistance of infective centres to UV radiation remains unchanged for a time after inoculation, after which it increases steadily and rapidly, until ultimately doses of the radiation much larger than those initially required to prevent lesion formation were ineffective. The reason for the lag period after inoculation before infective centres start to increase their resistance to irradiation (which differs characteristically with different viruses and virus strains) remained without any explanation until Siegel, Ginosa & Wildman (1957) found that it was abolished when plants were inoculated with free nucleic acid isolated from tobacco mosaic virus instead of with the intact virus. This has since been found to be so also with a tobacco necrosis virus (Kassanis, 1960) and with red clover mottle virus (Bawden & Sinha, 1961). The difference between the behaviour of the nucleic acids and intact viruses suggests that the nucleic acids dispense with some early step in the infection process required by intact viruses, and this perhaps provides the strongest evidence for the current idea that a first step in infection normally entails the nucleic acid moiety separating from the protein moiety of the virus.

This idea may be correct, and the results of some other experiments fit readily to it, as, for example, the fact that irradiated nucleic acid from tobacco mosaic virus is photoreactivable immediately it is inoculated to leaves, whereas particles of potato virus X have to wait for 30 minutes or more. However, not all experimental results fit to the idea. For example, as tobacco mosaic virus survives in irradiated leaves through the period while the leaves are photoreactivated and its nucleic acid does not, and as nucleic acid is much more susceptible to UV radiation than the intact virus, if the lag period is the time required for the nucleic acid to become free, irradiating leaves after the period has passed would be expected to inactivate more infective centres than are inactivated immediately after inoculation, but this does not happen (Bawden & Kleczkowski, 1960). This, however, does not disprove the idea, because in the normal process of infection nucleic acid may, after separating from virus protein, immediately combine with some other material, which may increase its stability and resistance to UV radiation. The combination may completely protect the nucleic acid from photoreversible kind of damage by UV, as does the combination with the virus-protein in the original virus particle. Therefore, the fact that infective centres irradiated after the lag period was over could not be photoreactivated to any greater extent than when irradiated earlier (Bawden & Kleczkowski, 1960) also does not disprove the idea of the nucleic acid separating from the virus-protein *in vivo*. Moreover, the effects of UV-irradiation and of photoreactivation on the leaf capacity were so great that they might well have obscured relatively small effects on the nucleic acid if this does become free.

Siegel & Wildman (1956) concluded that, when leaves of *Nicotiana glutinosa* are irradiated within a few hours after inoculating with tobacco mosaic virus, infective centres are destroyed at the rate at which the virus is inactivated when irradiated *in vitro*, and attributed the effect of UV on lesion number solely to inactivation of the virus *in vivo*. This seems wrong, because the extent to which

infective centres are affected by UV even immediately after inoculation depends on the condition of the plant and on whether irradiated leaves are exposed to daylight or kept in darkness, although the virus itself is not photoreactivable after UV-irradiation (Bawden & Kleczkowski, 1960). Among the factors that can affect susceptibility of infective centres to UV is temperature or illumination to which the plant has been exposed for a day or so before irradiation and inoculation, the age of the plant and the season of the year (Bawden & Kleczkowski, 1960; Bawden & Sinha, 1961).

Because the inactivation lines obtained by plotting logs of percentages of lesion survival against doses of irradiation were approximately straight when irradiations were done within a few hours after inoculation with a tobacco necrosis virus or tobacco mosaic virus, Bawden & Harrison (1955) and Siegel & Wildman (1956) concluded that they had disproved the dose hypothesis of infection and established that lesions develop from cells infected by single virus particles. However, as Bawden & Kleczkowski (1960) showed, the results of the irradiation experiments neither prove nor disprove that infections are initiated by single virus particles.

The claims by Bawden & Harrison (1955) and Siegel & Wildman (1956) that changes in the shape of the inactivation lines from previously straight lines to curves of " multiple-hit " type at different times after inoculation show the times when virus particles started multiplying also seem unwarranted, because they neither take into account possible changes in the condition of infected cells, which may alter susceptibility of the cells to UV radiation, nor the fact that to prevent lesion formation larger doses of the radiation are needed some hours after inoculation than immediately after. The larger doses are obviously likely to have more effect on the capacity of cells to support virus multiplication. Moreover, the results obtained by Bawden & Harrison (1955) with a tobacco necrosis virus do not justify the conclusion that the inactivation lines do change some hours after inoculation to a curve of " multiple-hit " type. The curve they drew is not typical of a " multiple-hit " curve, and in drawing this curve the numbers of lesions were transformed according to a dilution curve that related numbers of lesions to virus concentration in the inoculum, whereas the actual numbers should have been used. This transformation enhanced the curving, which is so slight that it seems reasonable to assume that the series of inactivation lines they obtained were all almost straight and differed from each other only in their slopes. The inactivation lines published by Siegel & Wildman (1956) for tobacco mosaic virus in leaves of *Nicotiana glutinosa* do change from straight lines to curves of " multiple-hit " type, but how to interpret this is uncertain. If the change does reflect the fact that infected cells now contain more than one virus particle, then it seems that a comparable stage is not detectable in French bean leaves infected with a tobacco necrosis virus, and a " multiple-hit " curve is not typical of all virus–host combinations.

The irradiation experiments with virus-infected leaves have revealed a number of phenomena. Whether further irradiation experiments alone can explain these phenomena, however, is doubtful. At the moment irradiation does provide a method of detecting

changes in infected cells that otherwise would remain undetectable, but other methods of study will probably be needed to show the nature of these changes.

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ISOTOPIC EXCHANGE OF PHOSPHATES IN SOIL

Review of Experimental Techniques and Results at Rothamsted 1952–1960

By

G. E. G. Mattingly & O. Talibudeen

Paneth and Vorwerk first used radiotracers to measure the surface-exchangeable ions of solids in suspension; their now classic experiments, done in 1922, used the lead isotope, Th B, to investigate insoluble lead salts. Only much later was this technique extended to the soil-phosphate system, using growing plants to sample the soil solution (Fried & Dean, 1952; Larsen, 1952). The historical development of this subject has been reviewed earlier (Mattingly, 1957a); this article summarises laboratory experiments and pot and field experiments at Rothamsted since 1952 to evaluate soil phosphate, using the isotope ^{32}P. The final section shows the extent of agreement between measurements in the laboratory and in pot experiments with soils from Rothamsted and Saxmundham Experimental Stations and Nurseries of the Forestry Commission.

Laboratory Measurements

(O. Talibudeen)

Introduction

In heterogeneous systems, isotopic exchange methods can be used to measure: (1) the concentration of the exchanging species at the surface of the dispersed phase, and (2) the bulk diffusion rate of the exchanging species into the dispersed phase. When applied to the soil phosphate : water equilibrium, it is difficult to separate these two measurements because adsorption sites on the soil surface and the surface chemistry of exchanging solid phosphates both vary.

These experiments were concerned with the extent and the rate of isotopic exchange in a fully dispersed soil : water system as influenced by intrinsic soil properties (e.g., carbonate content, pH, organic C content, mechanical composition, etc.) and extrinsic variables (e.g., soil : solution ratio, temperature, phosphate manuring, chelating and non-chelating organic anions, nature of the electrolyte in the equilibrating solution). The methods used are described in a series of papers (Talibudeen, 1954, 1957, 1958; Arambarri & Talibudeen, 1959, a, b, c).

Because of the complex nature of the soil-phosphate system, it is difficult to obtain unique constants for the rate of isotopic exchange which can be quantitatively related to extrinsic and intrinsic variables. However, semi-empirical constants have been obtained that are specific to each soil. To measure isotopic exchange rates,

it is convenient to maintain a constant concentration of the exchanging species in solution. In soil-phosphate equilibria this condition can be realised by maintaining equilibrium concentrations which are either very high (by adding excess soluble phosphate) or very low (by adding neutral salts). Each addition inevitably changes the soil-phosphate complex irreversibly, so that the resultant system bears little relation to the system it is desired to investigate. In our work the soil was brought to equilibrium with the phosphate concentration it would maintain in soil solution, small changes during isotopic exchange being corrected for by chemical analyses of the phosphate in solution.

Interpretation of the rate measurements presents two basic difficulties. Stable organic orthophosphates (e.g., nucleotide and phytate phosphorus) exchange isotopically at rates incomparably slower than adsorbed and particulate forms of inorganic phosphate. The isotopically exchangeable phosphate measured in the laboratory is principally related to the inorganic soil phosphate. Reliable estimates of the inorganic phosphate are therefore required to calculate the phosphate in the soil which could exchange isotopically in infinite time. Secondly, an approximate calculation shows that, on average, a *minimum* of 60 days would be required for complete isotopic exchange of the total inorganic phosphate, *if* the first-order rate constant for the slowly exchanging fraction controlled the exchange of *all* the slowly exchanging inorganic phosphate. Laboratory measurements show that small changes in specific activity of the phosphate in solution continue even after 12–14 days of continuous shaking. When these changes, measured at 48-hour intervals, are smaller than the mean error of the measurements ($\pm 3{\cdot}8\%$), a nearly constant figure for the isotopically exchangeable phosphate in the soil is evaluated.

The relation between the specific activity (SA) of the solution and time can be analysed semi-empirically in different ways by considering that: (1) two types of adsorption sites are responsible for isotopic exchange—those in which log (SA) and (SA) are linearly related to (time) and log (time) respectively; (2) log (SA) at small time-values decreases linearly with time; at large time-values (SA) decreases because of self-diffusion into the solid phosphate phase and therefore as a linear function of ($\sqrt{\text{time}}$); (3) the observed curvilinear decay in log (SA) with (time) in laboratory experiments is composed of two or more simultaneous first-order rate processes whose rate constants are a measure of the relative ease of exchange of groups of phosphate-adsorption sites in the soil complex.

Specific activity data for over a hundred arable soils from England and Wales have been examined by the third method; the results show that at least three groups of exchanging sites are involved with half-times of exchange 10–30 minutes, 5–15 hours and 40–60 hours. The phosphate in the equilibrium solution, which is removed from the soil during equilibration, is a part of the more rapidly exchanging groups of the total isotopically exchangeable phosphate. Experimental confirmation of this is given later. In aqueous suspension (0·02*M*-KCl) the phosphate in solution is less than a quarter of the total isotopically exchangeable phosphate, the rapidly exchanging fraction between a quarter and a third, the

slowly exchanging group between a half and two-thirds, and with few exceptions, the middle group is less than a twentieth. The phosphate in solution, the rapidly exchanging groups and the middle group make up P_r, the phosphate adsorbed on rapidly exchanging sites; P_r expressed as a fraction of P_e, the total exchangeable phosphate, is one of the semi-empirical constants P_r/P_e used to characterise the phosphate status of a soil.

In routine work, the amount of phosphate exchanged in 20 hours is taken to be the rapidly-exchanging phosphate P_r, and that exchanged in 170 hours as the " total " isotopically exchangeable phosphate P_e. Routine P_r values are over-estimated on average by about 25% of P_{slow} (where P_{slow} is the slowly-exchanging phosphate with an average half-time of exchange of 50 hours). P_e is usually only slightly under-estimated, because about 98% of the equilibrium P_{slow} exchange is completed in 170 hours. Hence P_r/P_e is an approximate value in routine determinations and less accurate than that derived from a full-scale rate-analysis.

The second " constant " used is the ratio P_e/P_t, where P_t is the total soil phosphate determined by perchloric acid digestion. This is a less sensitive and less accurate index than P_r/P_e, principally because P_t includes the inert and isotopically non-exchangeable organic phosphate, which cannot be estimated accurately.

Materials

Soils from four sources were used: (*a*) the classical plots at Rothamsted; (*b*) the nurseries of the Forestry Commission (Benzian, 1959); (*c*) N.A.A.S. experimental plots at Shardlow, Nr. Derby (Blood, 1957); (*d*) calcareous soils from selected arable sites supplied by the Soil Survey of England and Wales.

Extrinsic factors affecting the isotopically exchangeable phosphate

Various procedures have been suggested in the last 10 years to measure the isotopically exchangeable phosphate in soils. The aim has been to develop a routine laboratory procedure which gives values that not only correlate well with those in pot experiments but are equal to them. Before establishing a routine procedure it was necessary to evaluate quantitatively the influence of external variables on the isotopically exchangeable soil phosphate and to avoid any which significantly altered this numerical equality. The degree of success attained is discussed below (p. 261).

(a) *Soil : solution ratio.* The phosphate concentration in solution increased with soil : solution ratio, *but* the isotopically exchangeable phosphate measured at any one time *decreased* at a fixed and optimum rate of agitation (Talibudeen, 1954). The effect of increasing soil : solution ratios diminished at larger reaction times; the measurements indicated that soil : water ratios below 2 g. : 100 ml. did not alter the isotopically exchangeable phosphate.

(b) *Concentration of soluble phosphate added with* ^{32}P *for measuring isotopically exchangeable phosphate.* Most methods suggested for determining isotopically exchangeable phosphate use ^{32}P solutions of low specific activity (high phosphate content), and although good correlation is obtained with plant-derived indices, numerical equality is rarely observed. Experiments on a neutral Rothamsted soil

(Highfield) showed that, in the range of $3{\cdot}2 \times 10^{-7}M$ to $1{\cdot}5 \times 10^{-4}M$ phosphate, higher concentrations significantly decreased the isotopically exchangeable phosphate at any one reaction time (Talibudeen, 1957). To obtain a specific soil index it is necessary to add ^{32}P in a phosphate solution which does not appreciably alter the phosphate level in the equilibrium soil solution.

(c) *Organic anions.* Moderately high concentrations of anions (e.g., citrate and bicarbonate) which chelate cations in combination with soil phosphate are commonly used for evaluating phosphate residues; non-chelating anions (e.g., acetate) have also been used for this purpose. Isotopic exchange measurements are difficult with soils of very low phosphate status, because the phosphate concentrations to be measured in solution are so small. Very low concentrations of citrate ions were used to raise this phosphate concentration (Talibudeen, 1958). Two Rothamsted soils showing moderate response to phosphate were examined to estimate the influence of chelating and non-chelating organic anions at a $0{\cdot}001M$ level (Arambarri & Talibudeen, 1959a). Table 1 shows that soil pH directly influences the interaction of organic anions. The chelating citrate ion increases the total P_e in the slightly acid soil, but diminishes total P_e in the calcareous soil, although the rate of

TABLE 1

Influence of soil pH and chelating constants on the interaction of 0·001 Molar concentrations of organic anions with the isotopically exchangeable phosphate in Rothamsted soils.

Organic anion	Chelating constant for Ca	Isotopic exchangeability of soil phosphate: Highfield pH 6·7			Exhaustion land (superphosphate plot) pH 7·5		
	log (K_{Ca})	P_e	P_r/P_e	R_{slow} *	P_e	P_r/P_e	R_{slow} *
No organic anion ...	—	11·3	0·284	0·013	11·5	0·331	0·020
Phenyl-barbiturate	0·66	9·1	0·486	0·040	7·1	0·491	0·020
Citrate	3·15	16·3	0·760	0·044	9·5	0·476	0·037

* $R_{slow} \equiv$ 1st-order rate constant of slowly exchanging phosphate, in mg. P/100 g. soil/hour.

exchange R_{slow} of phosphate is increased equally in both soils. In contrast, the non-chelating barbiturate ion decreases total P_e in both soils, increasing R_{slow} in the acid soil but not altering R_{slow} in the calcareous soil. These figures illustrate some of the difficulties in using foreign ions, even in such low concentrations, to aid isotopic exchange determinations of the soil phosphate; P_e values with and without $0{\cdot}001M$-citrate are compared below (p. 261).

(d) *Nature of electrolyte in equilibrating solution.* Although isotopic exchange measurements in soil : water suspensions avoid specific ion interactions, they are impracticable in most soils. To ensure rapid and efficient separation of soil and solution and to provide a constant ionic strength without unduly diminishing the equilibrium phosphate concentration in solution, $0{\cdot}02M$-KCl solution was used. Experiments with NaCl, KCl and $CaCl_2$ solutions show that in strong electrolytes the valency of the cation has little effect on the total P_e (Arambarri & Talibudeen, 1959b).

(e) *Temperature.* Equilibrium phosphate concentrations in soil solution have a positive temperature coefficient, for which Aslyng (1950) gave an average value of 1–2% per °C. The temperature coefficient of the total labile phosphate for calcareous soils between 25° and 45° was between 0·8 and 6·6%, which emphasises the need to control temperature within ±1° in measurements of isotopically exchangeable phosphate (Arambarri & Talibudeen, 1959c).

The influence of intrinsic soil properties on the extent and rate of isotopic exchange of soil phosphate

The soils examined were divided into two broad groups—(*a*) calcareous soils containing >0·1% carbonate with pH values >7·2 in 0·01*M*-$CaCl_2$ or 0·02*M*-KCl; (*b*) non-calcareous soils containing <0·1% $CaCO_3$ in the pH range 3·7–7·0. Phosphate-retaining mechanisms and soil properties which would influence the extent and distribution of the soil phosphate in the two groups are quite different. The only common factor affecting soil phosphate distribution is the mechanical composition of the soil.

(a) *Calcareous soils.* The phosphate-retaining phase of primary importance is the carbonate fraction; this is conventionally referred to in soil analysis as *calcium* carbonate, although it may also often contain the carbonates of Mg, Fe, Mn and Zn.

Isotopic exchange measurements at Rothamsted on more than 50 soils from the United Kingdom and Spain showed that, although the rapidly exchanging phosphate, P_r, was unrelated to the carbonate content, the ratios P_r/P_e and P_e/P_t both increased linearly with decreasing carbonate content (Arambarri, 1960). Later work on four groups of soils selected from arable sites, where the carbonate and other mineral constituents were of similar origin within each group, showed that the ratio P_r/P_e decreased with increasing

TABLE 2

Decrease in the distribution of rapidly exchanging phosphate with increasing carbonate content in different soil groups (four soils in each group)

Origin of carbonate	Decrease in P_r/P_e per g. $CaCO_3$
Upper/Middle Chalk	$1·6 \times 10^{-2}$
Oolitic Limestone A	4·2
Magnesian Limestone	5·5
Lower Lias	9·3

carbonate content. In two of these soil groups with a large range of carbonate contents this relationship consisted of two linear portions. Up to 10% carbonate content the decrease in P_r/P_e was larger; at higher carbonate contents the change in P_r/P_e per unit change in carbonate content was less. Within the accuracy of measurement, the inverse linear relation between P_r/P_e and carbonate content was different for each soil group (Table 2). The surface exchangeable calcium (measured by isotopic exchange using the ^{45}Ca isotope in a "difference" method), in soils with similar carbonate contents from six sites, showed that P_r/P_e was

inversely proportional to the surface-calcium in the carbonate fraction. Surface areas, based on the surface density of Ca^{2+} ions on calcite surfaces, suggested that the " carbonate " crystallites in calcareous soils have an " effective " diameter of 0·25 μ, and therefore carbonate particles in size fractions larger than this diameter are very porous. In soils containing carbonate with the lowest specific surface, the first-order rate constant of the slow-exchanging phosphate fraction is at least three times as great as in soils with carbonate of high specific surface (Table 3). This table also illus-

TABLE 3

Relation between the first order rate constant of the slowly exchanging surface phosphate groups and the specific surface of the carbonate fraction in soils with similar carbonate contents (25–35% $CaCO_3$) of different geological origin

Carbonate	Specific surface (sq. m./g. $CaCO_3$)	R_{slow} (mg. P/100 g. soil/hour)
Coral Rag and Coralline Oolite ...	2·1	0·065
Portland Limestone	2·8	0·088
Magnesian Limestone	3·9	0·036
Chalk Marl Limestone	4·7	0·023
Lake Marl Limestone *	7·9	0·008
Synthetic Calcite (25 μ diameter) †	0·15	—

* Containing 52% $CaCO_3$.
† *Rep. Rothamst. exp. Sta.* for 1958, p. 50.

trates the variation in specific surface of the soil carbonate of different geological origins together with that of synthetic calcite. Isotopic exchange measurements show that added phosphate reverts to less-exchangeable forms at rates and in amounts that are directly proportional to: (1) the carbonate content (and thus to the total surface exchangeable Ca) in soils from one group containing carbonate of the same origin; (2) the surface-exchangeable calcium per g. $CaCO_3$ (or the specific surface) of the carbonate fraction in soils of similar carbonate content but of different geological origin.

Also, in each soil, P_e (as the quantity of phosphate exchanging) is linearly related to the phosphate in solution (as the intensity of phosphate), for the untreated soil and the phosphate-treated soil after 1, 2 and 6 months.

(b) *Non-calcareous soils.* Increase in soil acidity increases the aluminium (and iron) concentration (in particular, the activity of the Al^{3+} ion) in the soil solution, and the surface concentration of positively charged sites on soil minerals. The increase in Al^{3+} activity lowers the phosphate concentration in solution in several pairs of soils, where the soil, treated with equal amounts of superphosphate, has been maintained at different pH levels (Chakravarti, 1959). Table 4 shows that, in addition, decreasing soil pH affects P_e and P_r/P_e in the same way. The effect of soil pH on the isotopically exchangeable phosphate clearly illustrates the need for a reliable method for measuring the concentration of these positively charged sites on the soil surface. This may help to define the composition of surface-adsorbed layers formed in acid soils treated

with average agricultural levels of superphosphate. Table 4 also illustrates how the organic carbon content of the soil modifies the effect of soil pH on the water-soluble phosphate and the isotopically exchangeable phosphate. Thus, in a soil with less organic carbon the water-soluble phosphates and P_e decrease more with decreasing pH than in a soil with more organic carbon. This qualitatively indicates the blocking of positive adsorption sites by organic molecules or anions in soils with high organic carbon content, especially at lower pHs.

TABLE 4

Effect of soil pH and organic carbon content on water soluble phosphate and isotopically exchangeable phosphate

Soil	% Organic carbon *	pH	Total soluble aluminium ($\times 10^{-6}$ Molar)	Soluble phosphate	P_e (mg. P/100 g. soil)	P_r/P_e
Park Grass						
Plot 4(i) Unlimed	3·07	5·2	5·1	17·0	36·5	0·647
4(i) Limed ...	3·05	6·8	1·2	25·0	41·4	0·727
Shardlow Unmanured plots						
Plot A5	1·58	4·0	28·0	0·58	17·6	0·472
C5	1·67	5·0	3·1	1·5	21·3	0·545
E5	1·87	6·0	2·6	4·1	28·8	0·392(?)
Broadbalk Section V, Plot 8						
Sample 2 ...	1·19	5·3	—	4·4	22·9	0·477
3 ...	1·21	6·0	—	5·7	21·6	0·601
5 ...	1·19	7·5	—	9·7	30·7	0·635

* Walkley–Black Method (with acknowledgements to J. M. d'Arifat).

Cropping modifies the contrasts in P_r and P_e between unmanured and phosphate-treated soils, especially in soils with higher pHs from which much more of the added phosphate is removed. However, the effect of soil pH on the nature of phosphate *residues* can be evaluated by isotopic exchange measurements. Table 5 gives ratios calculated from *differences* in the P_r, P_e and P_t values for untreated and phosphate-treated soils from Shardlow at pH 4·0, 5·0 and 6·0. Thus, $\Delta P_r/\Delta P_e$ and $\Delta P_e/\Delta P_t$ values indicate that at lower pHs the residual phosphate is held in less exchangeable forms.

TABLE 5

The effect of pH on the isotopic exchangeability of phosphate residues in soils from N.A.A.S. Centre, Shardlow

Soil pH	$\Delta P_r/\Delta P_e$	$\Delta P_e/\Delta P_t$
4·0	0·436	0·700
5·0	0·805	0·828
6·0	0·831	0·722(?)

(c) *Phosphate manuring.* Much new information has been added to that already published (Talibudeen, 1958). It shows that:

(*a*) When water-soluble forms of phosphate are added to acid or calcareous soils the absolute values of P_r and P_e, as well as the proportion of added phosphate on rapidly exchanging sites (defined

by the ratios P_r/P_e and P_e/P_t), are significantly increased. In any one soil, this increase depends on: (1) the level of phosphate added; (2) the phosphate status of the soil initially; (3) the length of time the added phosphate has been in contact with the soil; and (4) in cropped soils the amount of phosphate removed from the soil by the crop before sampling. The effects of manuring and cropping are described below (pp. 257–259). The influence of the first three factors is briefly illustrated.

The P_r/P_e index is sensitive enough to detect the *residual* effect of 0·5 and 1·0 cwt. P_2O_5/acre (added as superphosphate) after 2 years, even when superimposed on the residual effect of previous manuring (Table 6). Larger changes in P_t/P_e have also been

TABLE 6

*Isotopic exchangeability of soil phosphate in Exhaustion Land two years * after a dressing of 0·5 and 1·0 cwt. P_2O_5 per acre as superphosphate*

Previous manuring †	Plot 5 No phosphate Ammonium salts (1856–1901)			Plot 9 Superphosphate (1856–1901)		
Cwt. P_2O_5/acre as superphosphate in 1957	0	0·5	1·0	0	0·5	1·0
Crop	P_r/P_e values					
Kale	0·540	0·570	0·595	0·589	0·605	0·620
Swede	0·490	0·557	0·576	No sampling		

* One year's cropping (kale or swede) followed by ploughing and one year's fallow.

† For full details, see Warren & Johnston, 1960.

observed (together with increases in P_r and P_e) under two very different sets of conditions (Talibudeen, 1958). In laboratory incubations when the soil was dressed with 10 mg. P/100 g., the isotopic exchangeability of the residue after 3 months' incubation was lower on the unmanured soil which also had the smaller P_r/P_e value (Table 7).

TABLE 7

Isotopic exchangeability after three months incubation at field capacity of phosphate added (10 mg. P/100 g. soil) to Exhaustion Land soils in relation to their phosphate status

Manurial history	Phosphate status of untreated soil	Isotopic exchangeability of 10 mg. P addition after three months	
	P_r/P_e	$\Delta P_r/\Delta P_e$	$\Delta P_e/\Delta P$
No manure	0·532	0·677	0·65
FYM (1856–1901)	0·689	0·743	0·70
Superphosphate (1856–1901)	0·666	0·771	0·70

(*b*) When very insoluble forms of phosphate (e.g., apatites) are added to calcareous soils little change in isotopic exchangeability of the soil phosphate can be detected (Talibudeen, 1958). However, the isotopic exchangeability of phosphate residues in acid soils

treated with rock phosphate or basic slag are not very different from superphosphate residues (Table 8).

(d) *Nature of exchangeable cations in the soil.* The isotopic exchangeability of soil phosphate is principally affected by the factors described above, although the exchangeable cations play a secondary but significant part in influencing it. In non-calcareous soils divalent exchangeable cations decrease the rate of exchange of the slowly exchanging phosphate without altering its extent;

TABLE 8

Isotopic exchangeability of phosphate residues from different sources in soils (pH 4·9–5·4) from Wareham Nursery, sampled in 1955

Phosphate source	ΔP_r	ΔP_s	ΔP_t	$\Delta P_r/\Delta P_s$	$\Delta P_s/\Delta P_t$
Gafsa rock phosphate	2·25	2·70	7·3	0·833	0·370
Basic slag	1·60	1·78	5·0	0·900	0·356
Superphosphate ...	1·70	1·85	4·9	0·920	0·378

this rate of exchange is also less sensitive to temperature than with soil saturated with monovalent cations. Thus, manurial treatments which shift the cation balance in the soil in favour of monovalent cations increase the rate of exchange of the slowly exchanging phosphate. It is suggested that this is caused by the decrease in Al^{3+} activity at the soil : water interface when changing from a divalent-cation-dominated soil to a monovalent one (Arambarri & Talibudeen, 1959b).

FIELD AND GREENHOUSE EXPERIMENTS

(G. E. G. Mattingly)

Radiation effects from ^{32}P

Conflicting reports have appeared on the magnitude and reproducibility of the effects of radiation on the growth of plants. Most workers have detected slight alterations in growth with both low and high levels of ^{32}P (see Mattingly, 1957a for references). In preliminary experiments in the greenhouse using ryegrass, dry weight and phosphorus uptake were the same when either 5 and 10 μC or 10 and 50 μC ^{32}P/pot were compared. However, less fertiliser phosphorus was taken up at the higher levels of radioactivity. There was no difference between effects of ^{32}P at different ^{31}P levels, or with different soils (Mattingly, 1957b). With barley, ^{32}P-labelled superphosphate gave the same yield of grain, straw and roots in the greenhouse and the same distribution of phosphorus in the crop as an equivalent amount of commercial superphosphate (Mattingly & Widdowson, 1958b). The effects of ^{32}P on growth and fertiliser uptake in greenhouse experiments were always small but reproducible, probably because the fertiliser was mixed uniformly throughout the soil. In field experiments, using superphosphate labelled with 0·7–1·4 mC ^{32}P/g. P, yields of barley and uptakes of phosphorus in the field were slightly lower than with commercial superphosphate (Mattingly & Widdowson, 1958b).

Field experiments

The main purpose of the field experiments using ^{32}P-labelled superphosphate was: (*a*) to establish whether the increased yields that usually result from applying water-soluble phosphates near the seed of cereals could be attributed to greater uptake of soil phosphorus, of fertiliser phosphorus, or both; (*b*) to measure by isotope dilution the total " pool " of isotopically exchangeable phosphate in the soil at different stages of growth and the increase in this " pool " from applying different non-radioactive phosphate fertilisers.

The uptake of soil phosphorus by barley. When barley grew rapidly, more total phosphorus and more phosphorus from the soil was removed in 26 days from plots receiving superphosphate than from plots without phosphate fertilisers. This effect was largest when the superphosphate was drilled with the seed; the *extra* phosphorus in the plants taken up from soil was then comparable with the phosphorus taken up from the fertiliser. Barley given broadcast superphosphate removed smaller amounts of *extra* soil phosphate. This effect did not persist until the crop was harvested, when, in seven out of eight comparisons, *less* soil phosphorus had been taken up when superphosphate was applied. Very similar results have been obtained elsewhere with wheat (Mitchell, 1957) and with oats (Verma *et al.*, 1959).

There are three possible explanations of the changes in uptake of soil phosphorus during growth: (i) radioactive superphosphate damages plants; (ii) superphosphate alters the growth pattern of roots; (iii) superphosphate " blocks " the removal of soil phosphorus. The first is unlikely, because increasing levels of ^{32}P usually decrease fertiliser uptake without greatly altering the total phosphorus removed by the crop. Consequently, the uptake of soil phosphorus should *increase* on applying a radioactive superphosphate. There is some evidence (Cooke, 1954) that the root system of peas, and presumably of other crops, is considerably more diffuse without phosphorus fertilisers than when superphosphate is either drilled or broadcast. This suggests that the roots of unmanured plants are in contact with a larger soil surface than those of plants receiving superphosphate. The exchangeable phosphate sites on soil surfaces may also be " blocked " by fertiliser phosphates, as in laboratory experiments (Talibudeen, 1957), which would further limit the removal of soil phosphate.

Isotope dilution with non-radioactive phosphate fertilisers. Experiments with ^{32}P-labelled fertilisers not only give information on the uptake of phosphorus from the fertiliser and soil but they also estimate the total " pool " of soil phosphorus sampled by the crop at different stages of growth. In the greenhouse, when soil and fertiliser are well mixed, the ratio of $^{32}P/^{31}P$ in the crop decreases only slightly during growth, as progressively more soil phosphate exchanges. In the field, however, this ratio falls more rapidly as roots take up phosphate from soil which is not mixed with the labelled fertiliser.

The total " pool " of soil phosphorus sampled by barley and fodder beet in the presence of drilled superphosphate (i) increased during growth, (ii) varied between the crops, and (iii) varied very

greatly in different years on the same site (Mattingly & Widdowson, 1958a).

The total "pool" sampled at harvest on one site was 37 and 55 lb. P acre for fodder beet and barley respectively; both values are larger than the total amount of phosphate removed by the crops. The smaller "pool" with fodder beet indicates that the root system of this crop does not remove phosphate from soil far from the fertiliser zone. When commercial non-radioactive phosphate fertilisers were broadcast in these experiments the increase in total labile phosphate in the soil was equal for fodder beet to the amount of phosphorus applied as superphosphate or dicalcium phosphate. With barley the increase was less than the total applied. Gafsa rock phosphate did not significantly increase either the "pool" of soil phosphate sampled or the yield of the crop in any experiment.

The conclusions from these experiments confirm and provide some quantitative explanations for results in other field experiments on fertiliser placement. Barley produces higher yields when superphosphate is drilled with the seed than when broadcast (Crowther, 1945). The experiments with ^{32}P show that (i) a higher proportion of phosphate is taken up from drilled than broadcast superphosphate, (ii) drilled superphosphate usually increases uptake of soil phosphate in the early stages of growth, and (iii) only part of the phosphate in superphosphate, when applied broadcast, increases the "pool" of labile soil phosphate sampled by the crop. In contrast, placing superphosphate for sugar beet, which has a similar root system to fodder beet, is very little more effective than broadcasting (Prummel, 1957), probably because the "pool" of phosphate sampled is restricted to the soil which is mixed with the broadcast fertiliser.

There is a fundamental difference between the interpretation of isotope dilution experiments in the field and in the greenhouse. In the greenhouse the root system is restricted to a known weight of soil. The amount of phosphate that exchanges *in unit weight of soil* can be calculated from the $^{32}P/^{31}P$ ratio in the crop.

In field experiments the amounts of soil phosphorus accessible *per acre* to the crop can be calculated from the ^{32}P ^{31}P ratio. However, phosphorus derived by the crop from soil mixed with the fertiliser cannot be directly distinguished from that derived from lower layers of soil, unless the limiting value of the ^{32}P ^{31}P ratio for unit weight of soil is known from a greenhouse experiment. In a field experiment in 1953, when barley grew very rapidly, all the dilution of fertiliser phosphorus by ^{31}P from the soil could be accounted for at harvest by the isotopically exchangeable phosphate estimated, from greenhouse experiments, to be present in the plough layer. In 1954, when the crop grew more slowly, the ^{32}P ^{31}P ratio was very small at harvest, and indicated that about one-half of the ^{31}P in the crop had come from below the layer of soil with which the fertiliser phosphate was mixed by harrowing (Mattingly & Widdowson, 1958b).

Evaluation of residues of phosphate fertilisers by isotope dilution. Similar methods using ^{32}P have been used to estimate the residual value of superphosphate in a field experiment with barley. The value in 1955 of the residues of superphosphate applied in 1954 was estimated from (*a*) yield, (*b*) phosphorus uptake and (*c*) changes in

the $^{32}P/^{31}P$ ratio in the crop. Six weeks after sowing, all three methods of evaluation showed that the residues were equivalent to about one-quarter as much superphosphate broadcast in 1955, and yields of grain at harvest also gave this value. Evaluations using phosphorus uptake and changes in the $^{32}P/^{31}P$ ratio in the crop were higher and equal to 40–50% of the amount of superphosphate applied in 1955. These results suggest that at harvest the root system of barley reached residues of superphosphate that had been buried by ploughing. The phosphorus taken up from these residues ("luxury uptake") did not increase yield but decreased the ratio $^{32}P/^{31}P$ in the crop (Mattingly & Widdowson, 1956).

Greenhouse experiments

Preliminary work (Mattingly, 1957b) established a standard technique for greenhouse experiments. A solution of monocalcium phosphate containing 2·0 mg. P, labelled with 10 μC ^{32}P, was mixed mechanically with 400 g. air-dry soil and 200 g. coarse quartz per pot. Perennial ryegrass (*Lolium perenne*, S23 strain), used as the test crop in most experiments, was cut at intervals of 3–4 weeks. This level of radioactivity was enough to measure the $^{32}P/^{31}P$ ratio in the grass up to 16 weeks from sowing. A few experiments were done using 100 g. soil labelled with 0·5 mg. P containing 5 μC ^{32}P/pot.

For the first cut of grass, the total amount of phosphate that exchanges per 100 g. soil during the greenhouse experiment is given by the equation

$$A = 0{\cdot}5 \left\{ \frac{(^{32}P/^{31}P) \text{ fertiliser}}{(^{32}P/^{31}P) \text{ crop}} - 1 \right\}$$

For several cuts of grass $(^{32}P/^{31}P)_{crop}$ is replaced by $(\sum_1^n {}^{32}P/\sum_1^n {}^{31}P)$, where $\sum_1^n$ is the sum of ^{31}P or ^{32}P removed in n cuts.

Comparison of phosphate fertilisers by isotope dilution. Experiments, similar in principle to those in the field, were done in the greenhouse to evaluate different phosphate fertilisers. Commercial, non-radioactive phosphate fertilisers were added to soils and compared with superphosphate by measuring (i) yield, (ii) phosphorus uptake, and (iii) changes in the ratio $^{32}P/^{31}P$ in the crop.

All three methods of evaluation showed that powdered dicalcium phosphate and silico-phosphate were equivalent to superphosphate in the greenhouse. However, rock phosphates gave much higher values by the isotope dilution method than from measurements of yield and phosphorus uptake, probably because ^{32}P was distributed unevenly in soil around particles of rock phosphate which dissolve slowly (Mattingly & Widdowson, 1956).

Measurement of the residual value of phosphate fertilisers. The principle of isotope dilution with ^{32}P-labelled orthophosphate has been used by several workers to estimate the residual phosphate in soil that remains isotopically exchangeable in greenhouse experiments. Table 9 gives estimated changes since 1901 in the "A" value of soils from the Hoosfield Exhaustion Land experiment at Rothamsted. Details of this experiment are given elsewhere (Warren, 1956; Warren & Johnston, 1960).

The values in line *a* were calculated, assuming 1 acre of soil weighs 2 million lb., from the average removals of phosphate by barley in the field reported by R. G. Warren in *Guide to the Experimental Farms* (Rothamsted, 1959, p. 26). "A" values in 1901 are not known, but were estimated from measurements on other plots at Rothamsted. Values in line *c* were determined in a greenhouse experiment.

TABLE 9

Removal of P by cropping and changes in "A" values on Hoosfield Exhaustion Land, 1901–1957

(All results in mg. P per 100 g. soil)

	Plot 1 (no P; no K)	Plot 3 (FYM before 1901)	Plot 9 (Superphosphate before 1901)
(*a*) P removed by cropping 1901–1957 ...	12	26	23
(*b*) "A" value in 1901 (estimated)	10	21	21
(*c*) "A" value in 1957	3	10	9
(*d*) Decrease in "A" between 1901 and 1957	7	11	12

Although the results involve some assumptions, they indicate that during 60 years only one-half of the phosphate removed by cropping came from the isotopically exchangeable "pool". The remainder has been derived from soil phosphate in an unknown chemical form that was not isotopically exchangeable in 1901.

In short-term field experiments the amount of phosphate taken up by the crops almost equals the decrease in "A". The "A" values of soils from the Four-Course rotation at Rothamsted decreased each year after applying superphosphate, but remained constant (at lower values than the superphosphate plots) after applying Gafsa rock phosphate. Rock phosphate appears to dissolve slowly in this calcareous soil, at a rate approximately equal to the rate at which phosphate is removed by the crops in the rotation (Mattingly, 1957b).

The increase in total phosphate content of soils (ΔP_t) from applying phosphate fertilisers can be determined by chemical analysis. The quantity of the residual phosphate in calcareous soils that is isotopically exchangeable has been measured in some greenhouse experiments from the increase in "A" values (ΔA) on plots receiving phosphate fertilisers. The values obtained for the ratio $\Delta A/\Delta P_t$ vary from 20 to 70% of the total residual phosphate (*Rep. Rothamst. exp. Sta.* for 1957, p. 61; for 1959, p. 50). This is greater than the range 26–56% quoted by Olsen *et al.* (1954) for calcareous soils in the U.S.A.

Some of the most important factors influencing the amount of residual phosphate that remains isotopically exchangeable are (i) pH, (ii) the quantity of phosphate removed by cropping, (iii) soil type, and (iv) the form of nitrogen fertilisers applied for long periods with superphosphate. The relative importance of (i), (ii) and (iv) is difficult to determine because they are interrelated, but the most

important single factor, on any soil type, appears to be removal of phosphate by cropping. This is illustrated below using soils from a rotation experiment on calcareous Boulder Clay at Saxmundham, details of which are given by Cooke *et al.* (1958).

TABLE 10

Effect of cropping in the field on the percentage of the residual phosphate ($\Delta A/\Delta P_t$) *that is isotopically exchangeable in calcareous soils from Saxmundham*

Field treatment	Mean yields of barley 1899–1956 (bushels/acre)	$\Delta A/\Delta P_t$ (%)
P	21	73
PK	23	71
NP	34	64
NPK	36	56

(P = 2 cwt. superphosphate/acre; N = 2 cwt. sodium nitrate/acre; K = 1 cwt. of potassium chloride/acre.)

Yields and amounts of phosphate removed by the crops were low without added nitrogen, and more of the residual phosphate in these soils now remains isotopically exchangeable.

Saxmundham soils have higher $\Delta A/\Delta P_t$ values than the calcareous soils at Rothamsted, on which this ratio varies from about 20 to 50%. The highest values at Rothamsted are on plots that have, at some time in their history, been acid from applying ammonium sulphate. The average value for $\Delta A/\Delta P_t$ in acid and very acid soils taken from nine field experiments in Great Britain and Japan was 70% (*Rep. Rothamst. exp. Sta.* for 1959, p. 49).

There are several limitations to experiments of this type using soil samples taken from field experiments. When the amounts of phosphate applied as fertiliser are small compared with total soil phosphate, ΔP_t is determined from the difference between two large quantities. In the experiments so far completed increases in phosphorus content shown by analysis have generally agreed closely with increases calculated by assuming the plough layer of 1 acre of soil weighs between 2·0 and 2·5 million lb.

The experiments referred to above show how much of the phosphate applied to soils as superphosphate remains isotopically exchangeable. They do not, however, give any direct evidence of the chemical form in which the phosphate residues exist in soil. Phosphate ions are probably adsorbed, rather than precipitated, because so large a proportion remains isotopically exchangeable.

Relationships between "A" values and crop growth. Yield of ryegrass, grown in the greenhouse and given optimum N, K and minor elements, is exponentially related, and uptake of phosphate by the crop linearly related, to the "A" values of soils. The equations below give typical relationships between yield (y) of ryegrass and the "A" values (x) for two groups of soils with very different physical properties:

Rothamsted soils (calcareous; 20–30% clay)

$$y = 17{\cdot}3 - 25{\cdot}2e^{-0{\cdot}161x}$$

Forest Nursery soils (acid; 1–10% clay)

$$y = 17{\cdot}5 - 18{\cdot}4e^{-0{\cdot}161x}$$

The maximum yields (17·3–17·5 g./pot) were the same for both groups when the experiments were continued for 4 months; this suggests that growth in the greenhouse was limited by phosphate and not by physical differences between the soils. The yield, per unit of isotopically exchangeable phosphate ("A"), was much greater on the lighter acid soils from nurseries of the Forestry Commission than on the heavier soils from Rothamsted. The more rapid growth of grass on the nursery soils has been attributed to the higher phosphate concentration, measured in 0·01*M*-$CaCl_2$, they maintain per unit of exchangeable phosphate (*Rep. Rothamst. exp. Sta.* for 1957, p. 59).

Table 11 shows the relationships between the uptake of phosphorus by ryegrass in three to four months and "A" values, found in four greenhouse experiments.

TABLE 11

Linear regression equations and correlation coefficients between uptake of phosphorus by ryegrass in the greenhouse (y) and "A" values of soil (x)

(All results in mg. P/100 g. soil)

Experiment	Brief description of soils	No. of soils	Regression equation	Correlation coefficient
P9	Rothamsted; calcareous	9	$y = 0{\cdot}546x - 0{\cdot}52$	0·998
	Forest Nurseries; acid	12	$y = 0{\cdot}668x - 0{\cdot}37$	0·986
P12	Rothamsted; calcareous	7	$y = 0{\cdot}217x - 0{\cdot}42$	0·977
	Saxmundham; calcareous	9	$y = 0{\cdot}290x - 0{\cdot}41$	0·991
P11	Acid and calcareous arable soils from C. and E. England	15	$y = 0{\cdot}418x - 1{\cdot}31$	0·870
P14	Acid and very acid soils from England, Wales, N. Ireland and Japan	24	$y = 0{\cdot}335x - 1{\cdot}15$	0·879

Phosphorus uptake and "A" are very highly correlated, especially so with soils from the same location. The differences between the regression lines for the different groups of soils in experiments P9 and P12 were both significant. The greater release of phosphate from the forest nursery soils agrees with the more rapid growth on them. No satisfactory explanation has yet been found for the differences between calcareous soils of similar clay content and composition derived from the Clay-with-Flints at Rothamsted and the Boulder Clay at Saxmundham in which the ratio P_r/P_e (Table 13) and phosphate concentrations in 0·01*M*-$CaCl_2$ are similar.

The high correlations in these experiments, and the fact that there is no outstanding discrepancy, may be partly explained by the technique used. In all experiments a "starter dose" of phosphate (0·5 mg. P/100 g. soil) was mixed with the soil. Although this is small compared with the "A" values of most soils (5–25 mg. P/100 g.), it may have maintained the concentration of phosphate high enough after germination for the root system to develop. This explanation is supported by evidence with both acid and calcareous soils that the *initial* rate of growth of grass in the greenhouse on soils with the same "A" value is most rapid when the phosphate concentrations in 0·01*M*-calcium chloride are high (*Rep. Rothamst. exp. Sta.* for 1957, p. 59; for 1959, p. 44).

The initial rate of growth of grass depends principally on phosphate potential, as predicted by Schofield (1955), but total yield and uptake of phosphorus increase with "A" and can, on some soils, be almost independent of phosphate potential. However, in Rothamsted soils potential (phosphate concentration) and quantity ("A") are closely correlated, so that either measurement predicts their phosphate status satisfactorily.

Relationships between Laboratory and Greenhouse Measurements of Isotopically Exchangeable Phosphate

Correlation of "A" and P_e

Table 12 summarises the correlations obtained between greenhouse ("A") and laboratory (P_e) values for isotopically exchangeable phosphate in arable soils.

Table 12

Summary of relationships between "A" and P_e *measured in 0·02M-KCl or in 0·02M-KCl + 0·001* NH_4 *citrate for arable soils*

No. of soils	Description	Electrolyte	Regression equation	Correlation coefficient
37	Acid, neutral and calcareous	0·02*M*-KCl	$A = 1{\cdot}067P_e + 0{\cdot}21$	+0·985
12	Acid	0·02*M*-KCl + 0·001*M*-NH_4 citrate	$A = 0{\cdot}771P_e + 0{\cdot}09$	+0·966
12	Calcareous	0·02*M*-KCl + 0·001*M*-NH_4 citrate	$A = 1{\cdot}238P_e + 1{\cdot}18$	+0·993

The 37 soils tested had clay contents between 1 and 30%, pH values (in 0·01*M*-$CaCl_2$) between 3·9 and 7·6, and P_e values between 1 and 32 mg. P/100 g. Values of "A" and P_e, measured in 0·02*M*-KCl, were very highly correlated, and "A" was numerically about 7% higher than the P_e values determined by the routine method. The regression equation shows that the total "pool" of soil phosphate sampled by ryegrass grown for 3–4 months in the greenhouse can be estimated quantitatively by isotopic exchange in the laboratory in about 7 days. The close correlations previously established between "A" and phosphorus uptake from soils (Table 11) will, therefore, also hold for P_e and phosphorus uptake in the greenhouse.

Values for P_e measured in 0·02*M*-KCl + 0·001*M*-NH_4Cit are also highly correlated with "A" (Table 12), but are about 30% higher than "A" on acid soils. This suggests that even 0·001*M*-NH_4Cit removed phosphate from acid soils with which ^{32}P ions do not exchange in the greenhouse. Acid reagents (0·3*N*-HCl; 0·002*N*-H_2SO_4; 0·5*N*-CH_3COOH and citric acid) often used in soil analysis also dissolve soil phosphate that does not exchange with ^{32}P ions in the greenhouse (*Rep. Rothamst. exp. Sta.* for 1958, p. 51). For calcareous soils P_e values in the presence of citrate are very highly correlated with, but less than, "A"; this is consistent with measurements in the laboratory (Table 1).

The correlations summarised above were obtained with arable soils. P_e is not always numerically the same value as "A" measured

by growing grass in the greenhouse for 3–4 months if the soils contain either mineral or bone phosphates, which continue to dissolve slowly during a greenhouse experiment, or organic phosphates from plant residues or soil organic matter, which mineralise slowly. The slow release of ^{31}P (with which ^{32}P did not exchange during the first few weeks in the greenhouse) from all these materials decreases the specific activity of the later cuts of grass. "A" values calculated in these circumstances may be anomalously high (Mattingly & Widdowson, 1956).

TABLE 13

Comparison of isotopically exchangeable P *values in laboratory and greenhouse experiments and yields of ryegrass in the greenhouse*

Manurial treatment in the field	mg. P/100 g. soil A_1	A	P_e	P_r/P_e ratio	g. dry matter per pot
Agdell Rotation, Rothamsted:					
NPK (*f*)	9·4	10·9	9·1	0·621	3·10
NPK (*c*)	6·6	7·5	7·8	0·483	1·87
PK (*f*)	8·7	9·5	9·3	0·619	3·28
PK (*c*)	5·0	6·4	6·7	0·544	2·02
O (*f*)	2·7	2·8	3·8	0·547	1·11
O (*c*)	2·6	2·4	3·5	0·352	0·78
Barnfield, Rothamsted:					
No nitrogen—					
PKNaMg	19·7	21·5	22·2	0·695	4·20
P	20·4	23·8	21·8	0·685	4·37
O	9·4	10·7	11·0	0·628	3·58
Sodium nitrate—					
PKNaMg	18·2	20·7	20·2	0·679	4·79
P	17·8	21·0	20·0	0·689	4·42
O	5·9	7·1	7·5	0·587	2·68
Ammonium sulphate—					
PKNaMg	32·4	33·9	29·6	0·750	4·65
P	31·0	36·1	30·1	0·810	4·40
O	9·3	10·4	12·0	0·585	3·09
Saxmundham, Rotation I:					
P	11·2	14·4	10·8	0·669	4·19
O	2·8	3·4	2·8	0·533	1·32
NP	10·9	13·2	9·3	0·621	4·16
N	2·6	3·3	2·8	0·473	1·20

Notes

Agdell Rotation: (*f*) = fallow rotation; (*c*) = clover rotation. Manuring 1848–1951; all fertilisers were applied at the following rates per acre once in four years. N = 2 cwt. ammonium sulphate + 18 cwt. rape cake; P = 4 cwt. superphosphate; K = 3 to 3½ cwt. potassium sulphate. For details of the rotation and soils see Warren (1958).

Barnfield: Rates of manuring/acre/year: N = 4 cwt. ammonium sulphate or 5 cwt. sodium nitrate; P = 3½ cwt. superphosphate; K = 4½ cwt. potassium sulphate; Na = 2 cwt. sodium chloride; Mg = 2 cwt. magnesium sulphate.

Saxmundham: Rates of manuring/acre/year: N = 2 cwt. sodium nitrate; P = 2 cwt. superphosphate; K = 1 cwt. potassium chloride. For details of the rotation and soils see Cooke *et al.* (1958).

Effects of manuring and cropping in the field on "A" and P_e

Table 13 gives values for P_e, the ratio P_r/P_e and "A" obtained with soils from long-term field experiments at Rothamsted and

Saxmundham Experimental Stations. Yields of ryegrass on these soils in a greenhouse experiment are also given. Values for P_r and P_e were obtained by the routine laboratory method (p. 248). P_r was measured after isotopic exchange for 20 hours and P_e after 170 hours. Two values are given for "A". The first, A_1, was calculated from the specific activity of the first cut of grass; the second is the weighted mean value during the experiment (p. 257).

Yields of beans and clover in 1956 and 1957 and phosphate solubility in 0·5*M*-$NaHCO_3$ show that soils from the clover rotation on Agdell now supply less phosphate to crops than soils from the fallow rotation (Warren, 1958). The "A" and P_e values, the P_r/P_e ratio, and yields in the greenhouse, are also lower on soils from the clover rotation (Table 13).

Yields in the greenhouse, P_e and P_r/P_e, are all higher on the *unmanured* soil from Barnfield "No N" plots than on NPK plots from the adjacent Agdell rotation. The application of 4 cwt. superphosphate/acre once in 4 years on Agdell has resulted in a net gain of 8 lb. P/acre/year on the NPK (fallow) and 5 lb. P/acre/year on the NPK (clover) plots (Warren, 1958). This gain has not maintained the total "pool" of isotopically exchangeable phosphate on the more heavily cropped Agdell soils at the present level of the unmanured Barnfield soil. Superphosphate applied at 2 cwt./acre annually at Saxmundham for 60 years, however, has maintained "A" values at higher levels (Table 13) than on Agdell. Yields in the greenhouse on soils from the P and NP treatments at Saxmundham were near the maximum for the experiment.

The supplementary manuring on Barnfield with K, Na and Mg, in the presence of superphosphate, for over 80 years has not affected either P_e or the ratio P_r/P_e. Continuous application of ammonium sulphate for 80 years lowered the pH of the soil to about 5·5 by 1955. These plots were limed in 1956 and are now neutral. The "A" and P_e values on plots receiving P or PKNaMg are 50% higher (Table 13) than the corresponding plots receiving sodium nitrate which have never been acid. This suggests that phosphate was dissolved by ammonium sulphate from particles of chalk and then adsorbed in an isotopically exchangeable form after liming.

Comparison of phosphate removed by ryegrass in the greenhouse with changes in P_e

Preliminary experiments (*Rep. Rothamst. exp. Sta.* for 1957, p. 60) showed that the differences between P_e values of soils before and after cropping in the greenhouse were *greater* on acid soils and *smaller* on calcareous soils than the total phosphate removed by ryegrass. These conflicting results were probably obtained because P_e values were measured by exchange in 0·02*M*-KCl + 0·001*M*-citrate in which P_e values are greater than "A" in acid soils and less than "A" in calcareous soils (Table 12).

Table 14 gives more recent results, in which P_e values were measured in 0·02*M*-KCl, for soils from two nurseries of the Forestry Commission. At both centres the soils have received superphosphate annually for over 10 years and have been maintained at

different pH values. The Kennington Extension nursery is on an old arable soil (*ca.* 10% clay) and the Wareham nursery on sand (*ca.* 1% clay).

TABLE 14

Comparison of phosphate removed by ryegrass with changes in P_e *for soils of different pH from Wareham, Dorset and Kennington, Oxon.*

	Kennington (KE27)					Wareham (W27)					Mean of all soils
Approximate pH ...	4·3	4·8	5·3	6·2	7·0	3·8	4·8	5·6	6·5	6·8	—
P_e (before cropping), mg. P/100 g. ...	14·4	13·6	15·4	17·6	18·3	12·6	13·6	16·1	19·9	17·1	15·9
P_e (after cropping), mg. P/100 g. ...	4·0	3·1	3·2	3·4	3·3	2·0	2·0	2·6	4·4	4·2	3·2
Difference, mg. P/100 g.	10·4	10·5	12·2	14·2	15·0	10·6	11·6	13·5	15·5	12·9	12·7
P removed by ryegrass, mg. P/100 g....	11·6	12·6	12·4	14·2	14·4	10·0	12·6	15·4	17·4	16·2	13·7

The decrease in P_e by cropping on both soils is almost equal to the phosphate removed by the ryegrass. This confirms that the laboratory method used here to measure P_e estimates quantitatively the " pool " of isotopically exchangeable phosphate in soil taken up by ryegrass over the whole pH range from 3·8 to 7·0.

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THE HISTORY AND WORK OF THE SOIL SURVEY

By

A. Muir & D. A. Osmond

Mankind must have taken an interest in soil from the time when "Adam delvéd and Eve span", but the first record appears to date from about the year 2210 B.C. when "Da Yu, the first emperor of the Hsia dynasty, took up the study of the soils of nine territories and classified them according to their colour, texture, geographical features and productivity for the purposes of evaluation and assessment of land taxes" (Tang, 1935). However, information about the distribution of the different kinds of soils was not collected systematically in other parts of the world until late in the 18th century. In his Presidential Address to the III International Congress of Soil Science, Sir John Russell said: "One of the striking services that soil science has rendered in recent years has been in surveying soils of the different countries and in the preparation of maps on which any desired part of the information can be represented. This is now recognised as an essential preliminary to all agricultural developments, reclamations and irrigation schemes, and it forms an integral part of any organised development of agriculture such as is now being carried out in many countries of the world. To start on important agricultural development without a preliminary soil survey is to run serious risk of disaster." The importance of the last sentence cannot be overstressed, and it should be borne in mind by all in charge of planning agricultural developments. That the warning has been heeded is apparent from the number of large enterprises in all parts of the world in which one of the first demands is for a soil survey to provide basic background information.

Although in 1665 a committee of the Royal Society circulated a questionnaire to numerous gentlemen asking for information about the kinds of soils in various countries, little was done to collect it and it was not recorded on maps. Later, in 1683, Dr Martin Lister presented to the Society "An Ingenious proposal for a new sort of Maps of Countries, etc.", which was intended to include both rocks and soils; but whether "soils" was used in the more modern sense is not clear—from Lister's description it appears that reference was made only to the top-soil. Not until the end of the 18th century were the first attempts made to prepare soil maps, when the authors of the General Views on Agriculture were requested to do so, and many of the Reports to the Board of Agriculture include maps of the distribution of the various soils in the country. Both top-soil and sub-soil were sometimes described; but land use or superficial geological deposits were often represented rather than soils.

By the 19th century geological maps had been produced and scientists interested in soil naturally turned to them, thinking that, if soil arose from the weathering of rock, then the distribution of soils

and rocks should be closely related—a belief that is valid only in part. It is not surprising, therefore, that early workers in soil survey, such as Gilchrist (1907), Hall and Russell (1911) and Newman (1912), should have been strongly biased towards using geological maps as the basis for soil maps. It is interesting to notice that these attempts at making soil maps were promoted by scientists working in southern England, where the areas surveyed were only thinly, if at all, covered by glacial drift and where it was feasible in many places to regard the underlying rock as the parent material of the soil. Consequently terms such as " Chalk soil ", " Gault soils ", " Lias soils " and so forth were commonly used and still usefully persist, though their sense may have been refined. However, when one of the best-known workers in British soil science, G. W. Robinson, made a soil survey in Shropshire he began to realise that the intimate relation between solid rock and soil was not so applicable in country that had been glaciated in past eras. This was more forcibly impressed on him when he was appointed Advisory Chemist in North Wales and initiated a soil survey of Wales.

In the course of innumerable visits to farmers, advisory chemists became aware of the many problems of plant growth which could not be entirely solved by applications of fertilisers but which were related to more fundamental and relatively unchangeable soil properties associated with the whole soil profile. They therefore began seriously to canvass the possibility of making maps of the soil as such. Maps were being made in the U.S.A. in which soil drainage and the nature of the subsoil were included in the description of what was called the soil series, but it was not until 1920, after a visit to the U.S.A. by W. G. Ogg, and later G. W. Robinson, that the importance of the soil profile and its morphology was appreciated in Britain and that attention was directed to the achievements of the Russian pedologists.

In Great Britain a sub-committee of the Development Commission considered, in 1919, the possibility of making soil maps which would, however, mainly be improved versions of the existing geological maps. From the accounts by Ogg and Robinson of the work in the U.S.A., it became clear that an independent body should undertake soil survey, though officials were reluctant to set up an organised survey. However, the Ministry of Agriculture agreed that certain Advisory Chemists should be allowed assistants to make soil maps. Incidentally, about this time G. W. Robinson introduced into the English language the words " pedology " to describe the scientific study of soils and " pedogenic " to describe the processes of soil formation and metamorphism.

In 1926 the American method of mapping soil series was demonstrated by G. Newlands and W. Dow at the first Soil Survey Conference, held at Harper Adams Agricultural College, when the first soil series map made in England was made of the College farm. After this it was decided to adopt the U.S. system of series and types (texture classes) for use in Great Britain, and at subsequent conferences and field meetings in England and Scotland methods were standardised for surveying and recording the information on maps.

In 1922 the Ministry's Conference of Advisory Chemists recommended that attempts to " correlate fruit culture with soil types

should be made in East Anglia and in the West Midland counties ", and during the next 20 years the results of several such fruit-soil surveys were published. As much of the work was started before 1926, soils were not described by series, and it was difficult to reconcile some of this older work with the newer ideas prevailing when it came to be published. The report of the fruit-soil survey in East Anglia (Wright & Ward, 1929) was published with maps showing the distribution of soil types (classes), and an attempt was made to relate plant growth to soil type. The second survey, in the West Midlands (Wallace *et al.*, 1931), described what are now recognised as soil series and drew attention to the inherent properties of the soil profile conducive to " good " or " bad " growth of fruit trees as evidenced by measurements of trees of comparable age and variety grown under similar systems of management. In addition, nutritional disorders were investigated and remedial measures suggested. Field trials and laboratory research were initiated on problems arising out of the survey.

These results and many others important to fruit growers and market gardeners were substantiated and extended by later reports on other fruit-growing areas, by Ward (1933) on West Cambridgeshire, Bane & Gethin-Jones (1934) on the Lower Greensand in Kent and Bagenall & Furneaux (1949) on the Hastings Beds, also in Kent. The last report contained the comment that " So local was the distribution of these soil series that it proved difficult to find a single orchard or plantation that was perfectly uniform in soil throughout ", and although series were described so that they could be identified in the field, no soil maps were made. In the fruit-growing district of the Vale of Evesham (Osmond *et al.*, 1949), similar plants were measured to relate the behaviour of fruit trees and horticultural crops with soil properties; the distribution of the series was recorded on maps. Together these surveys covered the largest fruit-growing districts and, besides obtaining information of use in solving some fruit-growing problems, they provided a sound basis for giving advice on planting new sites. The American series system was also used to describe the soils in the Vale of the White Horse (Kay, 1934) and later the strawberry district in South Hampshire (Kay, 1939). In her survey of the Vale of the White Horse Kay showed that Brenchley's rough correlation of weeds with soils could be made more definite and that certain weeds were associated with distinct soil series.

Other surveys, not all for their immediate practical value, were made in various places. G. W. Robinson, who founded a " school " of pedology in Bangor, made, with his staff, extensive oil surveys in North Wales. W. M. Davies and his colleagues began a survey around Harper Adams Agricultural College, following the demonstration of series mapping by Newlands and Dow; the work was eventually published in 1954 as one of the first of the memoirs of the Soil Survey of Great Britain. In the late 1920s W. G. Ogg began a soil survey of East Lothian after completing the mapping of the Edinburgh and East of Scotland College of Agriculture farm, and G. Newlands mapped parts of Aberdeenshire. A survey on the basis of soil texture was made of the district around Ayr by McArthur *et al.* (1932). After the Macaulay Institute was founded in 1930,

soil survey in Scotland was done mainly from there. The early interest was in classification and soil genesis, but some forest areas and, later, agricultural land were also surveyed (Muir, 1934, 1935; Muir & Fraser, 1940; Glentworth, 1944). During the progress of these various surveys many problems arose in the actual methods of surveying, as well as of classification of soils; these were discussed at the annual Field Meetings held in different parts of Britain, during which parties of surveyors mapped the same area and compared the results.

With surveys extending, there was evident danger that the same soil might be differently named by surveyors in different parts of the country; the identification of the parent material (when a drift deposit and not a solid rock) was a source of possible trouble, and there was obvious need for a standard system of classification. A Soils Correlation Committee was therefore set up to consider these matters, and members made tours in England and Wales in 1930 and 1935 and in Scotland in 1932 to examine soil series being mapped.

The Soils Correlation Committee was replaced in 1936 by the Soil Executive Committee with similar functions, and in 1939 it was decided to set up the Soil Survey of England and Wales with Prof. G. W. Robinson as Director; a close connexion was maintained with the soil survey in Scotland conducted from the Macaulay Institute. A small committee, formed in 1938 to discuss colouring soil maps, prepared a working classification of soils as then known. This, together with a classification of parent materials prepared by the Correlation Committee, was included in a *Soil Survey Field Handbook* by G. R. Clarke which provided standardised methods for describing soil profiles, classifying soils and colouring maps that remained in use for many years. However, recent advances, both at home and abroad, in the technique of describing and mapping soils showed deficiencies in the *Handbook* which has now been revised and a new edition published (1960).

During the War soil survey almost ceased, but the knowledge acquired was of great use in the recommendations made by committees for ploughing up old grassland and allocating the limited amounts of fertilisers. The survey officers in effect became advisory officers, and when the National Agricultural Advisory Service was formed after the War, some joined the new organisation. The headquarters of the Soil Survey of England and Wales was transferred to Rothamsted Experimental Station, and A. Muir was appointed Head of the Survey in 1946. In Scotland the Macaulay Institute continued to be the headquarters of the Scottish Soil Survey. To guide the Surveys, a Soil Survey Research Board was set up by the Agricultural Research Council.

Until recently, mapping in England and Wales was done at 1 : 63360, and four memoirs (Crompton & Osmond, 1954; Avery, 1955; Roberts, 1958; Ball, 1960) with soil series maps have so far been published and a map of the soils of the Pwllheli district without a memoir (1958); several more maps and memoirs are nearly completed. Most of the surveys are done to obtain knowledge of the distribution of soils, but the Glastonbury district was surveyed because of the teart disorder of cattle in Somerset. Although the

survey did not solve the problem, it directed attention to the prevalence of the trouble on particular soils associated with the Lower Lias formation, which were later shown to promote unusually high contents of molybdenum in the pasture plants. Since then excess or deficiency of this element has been shown to be important in animal and crop husbandry in many parts of the world. Deficiencies of other minor elements have come to light and their correlation with soil series shown in other parts of Great Britain. As might be expected, some of these minor-element troubles in this country depend on the kind of rock from which the soils are derived. Thus, cobalt deficiency is linked with certain areas of granite in Devon and Cornwall and with some areas of Old Red Sandstone in the north of Scotland. Nevertheless, considerable changes in minor-element content can be produced in soils by differences in drainage.

In Scotland the survey is made mainly at 1 : 25,000 and four memoirs (Glentworth, 1954; Muir, 1956; Mitchell & Jarvis, 1956; Ragg, 1960) with maps have been published: others are being prepared. Mainly at the instigation of the National Agricultural Advisory Service, reconnaissance mapping at 1 : 25,000 has been adopted in England and Wales since 1959, and a considerable area has been mapped on this basis; the surveyors are stationed at the regional headquarters of the National Agricultural Advisory Service, with mutual benefit to both.

Many official bodies are now taking heed of Sir John Russell's words quoted above, and requests for surveys of particular areas are numerous. All the Experimental Husbandry Farms, sites of many field experiments of the National Agricultural Advisory Service and several county farm institutes have been surveyed, and it is hoped that the relation between crop, management and soil will become better established than now and so allow better advice to be given and yields better predicted. Similar surveys have been made for the Forestry Commission, and a map is being made of the soils in Thetford Forest—the largest in England.

It would be tedious to detail all the *ad hoc* surveys (see *Annual Reports*) undertaken, but some of the more interesting deserve mention. In 1950 a preliminary survey, which was later extended, was made of the Wentlloog and Caldicot Levels (Glamorgan) where 26,000 acres were mapped to determine the extent of poorly drained soils on which productivity is limited although their inherent fertility is high. In the same year a survey was initiated of some of the "moss" lands in Lancashire: the information provided on the differing kinds of peat soils, their thickness, the nature of the underlying mineral soil and their agricultural potential aroused so much interest that the survey was extended; by 1957 35,000 acres were mapped, and the report was incorporated in the recommendations made about their use and drainage. One of the problems of opencast iron- and coal-mining is to restore the sites to agricultural use afterwards, and several surveys have been made at different times in this connexion: the rate at which large agriculturally intractable blocks of limestone weather and the rate of soil formation on these highly disturbed, heterogeneous materials has also been studied. Deposits of Shirdley Hill Sand in Lancashire subjected to certain pedological processes yield a quartz sand highly suitable for

glass-making. In waterlogged soils, particularly under a peaty organic covering, iron oxides are strongly reduced, and the reduced iron readily diffuses out of the upper layers, leaving a strongly bleached residue. When this occurs in the Shirdley Hill Sands, it leaves an excellent glass sand. Thus the soils when classified genetically fall into groups that fairly closely represent glass-sand quality. As much of the deposit was in an area proposed for a new town, a survey was made in 1958–59 to determine the extent of the glass-sand; its distribution and quality were mapped, and as a result a sequence of building was arranged so that this valuable resource should not become unusable as happened in a district built over earlier.

Much horticultural land is level and well-drained, so it is often coveted for building sites, and surveys have been made to delimit its extent, notably in Sussex and Guernsey. The whole of Guernsey was surveyed, and in Sussex the survey is being extended to cover the whole coastal district. In connexion with the proposed routes of new roads, by-passes, etc., in various parts of England, soil profiles were described at frequent intervals and samples supplied to the Road Research Laboratories for investigation. Surveys have been made of several large areas, proposed as the sites of new towns, where there is a possibility of the loss of much high-class agricultural land. This use of survey information dates from the close of the Second World War when land classification maps were made of Herefordshire, Worcestershire, Shropshire, Warwickshire and the environs of Birmingham for the West Midland Group on Post-War Reconstruction and Planning (West Midland Group, 1946, 1947, 1948). Specifications of site and soil were drawn up by a committee, on which the Soil Survey was represented, to enable three " qualities " to be differentiated, and maps and reports were presented on this basis. A similar survey was made later in Somerset, Gloucestershire and Wiltshire for the Reconstruction Research Group (1947) of Bristol University, and the method is now being used by the Ministry of Agriculture, Fisheries and Food in surveys of potential horticultural land. Maps and reports have also been made more recently by the Soil Survey on similar projects for new towns in the north of England and in connexion with post-war planning in the Midland Valley of Scotland.

Although these *ad hoc* surveys mean there is less time for " routine " surveys, the two do not always conflict. Sometimes the information needed exists in the routine survey and needs only to be put in an appropriate form for immediate use; at others the request leads to an extension of the survey, or, information from an *ad hoc* survey becomes of use when it is later decided to make a routine survey of that particular district.

In addition to preparing maps and memoirs and reports on specific areas, the Survey publishes an *Annual Report* (1950–59) describing the year's work, with brief descriptions of new soil series and *ad hoc* surveys.

A soil map of Great Britain (1 : 2,500,000), made from a reconnaissance survey by the staff at 1 : 625,000, is incorporated in the soil map of Europe prepared by the Food and Agriculture Organisation of the United Nations, and officers of the Survey take part in

international discussions concerned with soil classification and the preparation of a soil map of the world.

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ABSTRACTS OF PAPERS

Physics Department

General Papers

1.1 Monteith, J. L. (1960). The physics of dew formation. [In Hebrew.] *Mada, Jerusalem*, **5**, 13.

1.2. Penman, H. L. (1960). Weather problems in agriculture. *Nature, Lond.* **187**, 995–996.

1.3. Penman, H. L. (1960). The general principles of irrigation. *Scot. Agric.* **42**, 140–142.

Research Papers

1.4. Currie, J. A. (1961). Gaseous diffusion in porous media. III. Wet granular materials. *Brit. J. appl. Phys.* **12**. (In the press.)

The diffusion of hydrogen through granular materials partly saturated with water was measured by a non-steady state technique previously described. The two types of sample used consisted of solid particles (unimodal pore-size distribution) and porous particles (bimodal pore-size distribution), and all measurements were made on samples being dried from saturation. Coefficients of diffusion D were calculated, and for the range over which the larger pores were emptying the empirical equation $D = D_g(\epsilon/\epsilon_t)^\sigma$ fitted all materials, where ϵ is the fractional air-filled volume, ϵ_t is the volume occupied by the larger-pore phase, and where D_g is the diffusion coefficient when only this phase is air-filled. For all materials $\sigma = 4$ whether the samples were uniform or of mixed sizes. No such relationship existed over the subsequent range in which the smaller pores were drained. Over this range D must be a function of at least five independent variables: the total porosity ϵ_T, the crumb porosity ϵ_c, the shape factor for the crumbs or inter-crumb pores k, the shape factor for the particles forming the crumbs or crumb pores k_c and the moisture content of the sample. The spatial distribution of pores within a porous medium can be as important as the sizes of the pores. The factors k and m, previously introduced as particle-shape factors, now have a greater significance as measures of the geometrical complexity of a porous system. Adding water can either increase or decrease the complexity, depending on the amount added and the nature of the system. The agricultural significance of diffusion between the crumbs (D_e) and within the crumbs (D_c) is discussed, and it is suggested that D_e, or its associated complexity factor k_e, might be used as an index of soil structure.

1.5. Monteith, J. L. (1960). Micro-meteorology in relation to plant and animal life. *Proc. Linn. Soc.* **171**, 71–82.

Micrometeorology is the study of atmospheric processes at the earth's surface. If the leaves of plants and the skins of animals are regarded as extensions of that surface, micrometeorological principles can help the biologist to investigate the influence of physical environment on living material. Two examples are considered in illustration. First, the surface temperature of plants and animals and the cooling produced by evaporation are discussed in terms of heat-balance equations. Second, it is shown that the uptake of carbon dioxide by a field crop can be measured by a micrometeorological technique.

1.6. Monteith, J. L. (1961). An empirical method for estimating long-wave radiation exchanges in the British Isles. *Quart. J. R. met. Soc.* **87**, 171.

From radiation measurements at Kew Observatory (tabulated by Lönnqvist), the effective emissivity of the atmosphere ϵ, defined as the ratio of

incoming long-wave radiation to black-body radiation at screen temperature, can be related to optical path m (cm.) by

$$\epsilon = 0{\cdot}70 + 0{\cdot}22 \log m$$

with standard deviation $\pm 0{\cdot}018$. The relation between m and surface vapour pressure e (mb.) found from Belasco's (1952) air mass analysis is

$$\log m = 0{\cdot}29\sqrt{e} - 0{\cdot}80$$

giving

$$\epsilon = 0{\cdot}53 + 0{\cdot}065\sqrt{e}$$

almost the same as Brunt's equation from Benson data.

Net long-wave radiation L over short grass can be calculated from

$$L = (1 - C)(\epsilon - 1)\sigma T_A^4 + C\Delta L_1 - \Delta L_2$$

where C is fractional cloudiness; σT_A^4 is black-body radiation at screen temperature; ΔL_1 is a correction for the difference between T_A and cloud base temperature; and ΔL_2 for the difference between T_A and surface radiative temperature. From Roach's Kew data, $\Delta L_1 = -18$ cal.cm.$^{-2}$day^{-1}; and ΔL_2 varies with season from -12 cal.cm.$^{-2}$day^{-1} (December) to $+20$ cal.cm.$^{-2}$day^{-1} (June). Throughout the British Isles, annual mean L with $C = 0$ is close to -200 cal.cm.$^{-2}$day^{-1}, and for real values of C,

$$L = 178C - 200 \text{ cal.cm.}^{-2}\text{day}^{-1}.$$

Estimated annual net (total) radiation is 29 k.cal.cm.$^{-2}$ with little variation over the British Isles.

1.7. Monteith, J. L. & Szeicz, G. (1961). The radiation balance of bare soil and vegetation. *Quart. J. R. met. Soc.* **87**, 159.

Incoming short-wave radiation (S), reflected short-wave radiation (αS) and net radiation (R) were measured over bare soil and crops from 1957 to 1959, and net long-wave radiation (L) was deduced from

$$R = (1 - \alpha)S + L$$

For grass, α increased from 0·23 at solar elevation 60° to 0·28 at 20°, with daily mean 0·26. For bare soil, the corresponding increase was from 0·16 to 0·19, with mean 0·17. In mid-June L for bare soil decreased from $-0{\cdot}1$ cal.cm.$^{-2}$min.$^{-1}$ during the night to $-0{\cdot}4$ cal.cm.$^{-2}$min.$^{-1}$ in the early afternoon. For long grass, in August, the corresponding change was from $-0{\cdot}05$ to $-0{\cdot}22$ cal.cm.$^{-2}$min.$^{-1}$ Under clear skies the incoming long-wave component varied much less than the outgoing component, and net flux L was closely related to surface temperature.

With a "heating coefficient" $\beta = -dL/dR$, the observed linear dependence of R on S in the absence of cloud may be expressed as

$$R = S(1 - \alpha)/(1 + \beta) + L_0$$

where, formally, $R = L_0$ when $S = 0$. For grass, sugar beet and potatoes, β lay between 0·15 and 0·22, with a variation which may depend on wind speed rather than on crop. The value for dry bare soil was higher (0·41) because there was greater surface heating.

Measurements under clear skies and over grass at Cambridge and Kew agree well with Rothamsted values ($\beta = 0{\cdot}22$, $L_0 = -5{\cdot}9$ cal.cm.$^{-2}$hr.$^{-1}$). Over Nebraska prairie, $\beta = 0{\cdot}25$, $L_0 = -4{\cdot}5$ cal.cm.$^{-2}$hr.$^{-1}$ from selected observations during Projects Great Plains and Prairie grass.

1.8. Penman, H. L. (1960). Evaporation. *In: British manual of water supply practice.* London, Institution of Water Engineers.

After setting out the water balance equation for a catchment area the individual terms are considered separately. Evaporation is discussed, first through the statistical approaches of Turc and Tamm, and then via Thornthwaite to more purely physical approaches. A dozen examples are given of new computations of mean monthly potential transpiration for representative sites in the British Isles, and a complete table of mean annual rainfall and mean annual run-off for all British catchments having more than 4 years of records. As expected, the annual value of rainfall *minus* run-off is usually less than the calculated potential transpiration because of checks to transpira-

tion during dry summers, and the soil physics of this is considered with special reference to the ideas of Veihmeyer. The water balance of two catchments is analysed. The first, for the Stour, is a review of old work: the second, for an area in the Harz mountains in Germany, is new. Five years' measurements give the mean annual difference between rainfall and run-off as 22·8 inches for a forest area and 20·6 inches for a grass area. Calculation of potential transpiration, from weather data taken in the neighbourhood, gives a mean annual value of 22·6 inches, which is brought to 20·1 inches if evaporation is assumed to be zero during the months when the grass is under snow.

Chemistry Department

General Papers

2.1. Cooke, G. W. (1960). The use of fertilisers on grassland. *S.C.I. Monogr. no. 9* ("Chemical Aspects of the Production and Use of Grass"), pp. 5–18.

2.2. Cooke, G. W. (1960). Optimum fertiliser dressings. *J. R. agric. Soc.* **121**, 21–33.

2.3. Cooke, G. W. (1960). Soils and fertilisers. *J. R. agric. Soc.* **121**, 170–191.

2.4. Cooke, G. W. (1960). Några synpunkter på kemiska undersökningar av jordens bördighet. (Some chemical aspects of soil fertility research.) [In Swedish.] *K. Skogs-och LantbrAkad. Tidskr.* **99**, 151–170.

2.5. Cooke, G. W. (1960). The right place for fertilisers. *Pract. Power Fmg*, **24** (no. 3), 39–47.

2.6. Mattingly, G. E. G. (1959). Crops. *Rep. Progr. appl. Chem.* **44**, 268–276.

2.7. Widdowson, F. V. (1960). Fertiliser placement. *N.A.A.S. Quart. Rev.* no. 48, 147–150.

Research Papers

2.8. Arnold, P. W. (1960). Potassium-supplying power of some British soils. *Nature, Lond.* **187**, 436–437.

British soils containing similar amounts of total K vary greatly in their ability to release non-exchangeable K. For soils which had not received heavy K manuring the K released to crops increased with increases in the amounts of fine clay ($<0{\cdot}3\ \mu$) and also with the K content of the fine clay. Amounts on the coarse clay ($0{\cdot}3$–$2{\cdot}0\ \mu$) were poorly correlated with K-supplying powers of the soils. Only one soil, derived from glauconitic Malmstone, released significant amounts of K from large particles.

2.9. Arnold, P. W. (1960). Nature and mode of weathering of soil-potassium reserves. *J. Sci. Fd Agric.* **11**, 285–292.

In most partially weathered mineral soils only a small part of the total K is readily exchanged with other ions; the bulk occurs in non-exchangeable (or difficultly exchangeable) forms in potash feldspars, micas and micaceous clays, all of which are potential sources of K for plants. Some of the principles underlying the weathering processes in feldspars, trioctahedral and dioctahedral micas are discussed. The ease with which freshly cleaved potash feldspar releases K to water does not indicate that feldspar weathers easily; in soil feldspar is protected by a surface covering of its own decomposition products. Trioctahedral micas are less stable to weathering than dioctahedral micas, particularly during the early stages of K-depletion; the stabilities of these

two main groups of micas differ more than can be accounted for in terms of Fe^{++} contents. For micas and micaceous clays the relationships between parent lattices and weathering products must depend very largely on the extent to which layer-charges have decreased on weathering.

2.10. Bremner, J. M. (1960). Determination of nitrogen in soil by the Kjeldahl method. *J. agric. Sci.* **55**, 11–33.

The reliability of the Kjeldahl method for determining N in soils was investigated. The same result was obtained by a variety of procedures, including methods which recovered various forms of N not determinated by the common Kjeldahl methods used for analysing soils. It was concluded that little, if any, of the N in the soils examined was as highly refractory N compounds as compounds containing N–N or N–O linkages. Results by the A.O.A.C. method of determining N in soils were 10–37% lower than those by other methods tested, but satisfactory results were obtained by this method by increasing the period of digestion recommended. Ammonium-N fixed by clay minerals is determined by the Kjeldahl method. Se and Hg are more effective than Cu for catalysing Kjeldahl digests of soil. Conditions leading to loss of N in using Se are defined, and difficulties in using Hg are discussed. The most important factor was temperature of digestion with H_2SO_4, this is controlled largely by the amount of K_2(or Na_2)SO_4 used. The period of digestion required depended on the concentration of K_2SO_4; with low concentration (e.g., 0·3 g./ml. of H_2SO_4) it is necessary to digest for several hours; but with high concentrations (e.g., 1·0 g./ml. H_2SO_4) short digestion was enough. Catalysts affected the rate of digestion with low but not with high salt concentrations. N is lost from digestions above 400°. The amounts of H_2SO_4 consumed by various mineral and organic soils during digestion were measured. Semi-micro Kjeldahl methods gave the same values for soil N as macro methods.

2.11. Bremner, J. M. & Jenkinson, D. S. (1960). Determination of organic carbon in soil. I. Oxidation by dichromate of organic matter in soil and plant materials. *J. Soil Sci.* **11**, 394–402.

Organic C contents of a range of soils and of various materials (mostly from plants) were determined by the titrimetric methods of Tinsley and Walkley and Black, they were compared with those obtained by Shaw's wet combustion method. Tinsley's method gave more reliable results with soils than Walkley and Black's method; neither was satisfactory for precise work. Both give high results with organic materials less oxidised than elemental C and low results with organic materials more oxidised, but this effect was masked with materials that do not react completely under Walkley and Black conditions. Quantitative results were obtained on a range of whole plant materials with both Tinsley's and Walkley and Black's methods. C contents determined by Tinsley's method for a range of pure organic compounds agreed with theory. Tinsley's method does not give quantitative results with certain soils, partly because of the oxidation level of the organic matter in them, and partly because oxidation is incomplete.

2.12. Bremner, J. M. & Jenkinson, D. S. (1960). Determination of organic carbon in soil. II. Effect of carbonised materials. *J. Soil Sci.* **11**, 403–408.

A variable, and often substantial, amount of the C in carbonised materials, like coal, charcoal and graphite, is oxidised when these materials are treated with acid dichromate in determining soil organic C. These methods cannot be used to detect carbonised materials in soil, or to discriminate between C in carbonised materials and C in soil humus.

2.13. Jenkinson, D. S. (1960). Scintillation counting of carbon-14. *Nature, Lond.* **186**, 613–614.

A method was developed for counting high activities of ^{14}C which is rapid, precise and independent of the chemical form of the ^{14}C.

2.14. Rodriguez, J. & Mattingly, G. E. G. (1960). Estimation of potassium in soils by determination of ^{40}K content. *J. Sci. Fd Agric.* **11**, 717–721.

The K contents of 38 soils from Great Britain and Spain were estimated by determining their count rates in a cylindrical Geiger–Müller tube. The count rate was converted to % K from a calibration curve obtained with mixtures of powdered quartz and minerals of known K content and density. The mean amount of K in 26 soils from Central, Eastern and Southern England was 0·19% K higher by counting than by chemical analysis because they contained other radioactive elements. The radioactivity of these soils, other than that from K, was equivalent to approximately U 2·5 p.p.m. and Th 18 p.p.m. Results by chemical analysis and by counting differed more with 12 soils from Scotland, Wales and Spain than with soils from England.

The standard error of the mean of duplicate estimations of the K content of soils was about $\pm 0{\cdot}075\%$ K for the radio-chemical method, and $\pm 0{\cdot}023$ to $\pm 0{\cdot}026\%$ K for two chemical methods.

2.15. Widdowson, F. V., Penny, A. & Cooke, G. W. (1960). The value of calcium nitrate and urea for main-crop potatoes and kale. *J. agric. Sci.* **55**, 1–10.

Twenty-two experiments on main-crop potatoes and seven experiments on kale in 1955–57 compared calcium nitrate and ammonium sulphate applied to the seedbeds before planting; urea was also tested in 15 of the potato experiments and five of the kale experiments in 1956–57. Calcium nitrate usually gave less potatoes than ammonium sulphate, particularly with the high dressings. Smaller yields with the nitrate were usually associated with severe checks to early growth occurring during dry springs and with dressings concentrated too close to the seed, but yields were also smaller at some centres where early growth was not checked. Calcium nitrate and ammonium sulphate were roughly equivalent for kale when nitrate did not damage germination; but heavy dressings of nitrate in the seedbed greatly decreased kale plant numbers when there was little rain after sowing. Granulated urea tested in 1956 contained 4·5% of biuret, and it delayed emergence and affected plant establishment seriously in several of the potato experiments; damage increased with the level of manuring and was accentuated when dressings were broadcast over furrows before hand-planting. Yields given by this batch of urea were less than with other N fertilisers, and when 1·5 cwt. N/acre was applied they were less than with no nitrogen at all. Purer crystalline urea (having less than 1% of biuret) used in the 1957 experiments did not affect emergence of potatoes and gave yields similar to those from ammonium sulphate. There were similar effects in the kale experiments; granulated urea containing much biuret damaged germination severely in 1956; the purer products containing little biuret used in later years affected plant numbers at one centre in 1957 and at the single 1958 centre. Where the establishment of kale was unaffected, urea and ammonium sulphate gave similar yields. Dressings applied partly to the seedbed and partly in mid-season gave slightly higher average yields of kale than an equivalent total amount of N all applied before sowing.

2.16. Widdowson, F. V. & Shaw, K. (1960). Comparisons of casein and formalised casein with ammonium sulphate, calcium nitrate and urea for Italian ryegrass. *J. agric. Sci.* **55**, 53–59.

Single dressings of ammonium sulphate and of casein were of similar value at each of three cuttings of Italian ryegrass in 1956. Casein treated with formalin released N much more slowly and was of little value in the early part of the growing season. Formalised casein produced significantly higher yields than casein at the later cuttings in 2 years, but aggregate increases from this material were much less than those from untreated casein in each season. Formalised casein increased yields considerably in the year after application. Single dressings of formalised casein were also compared with " repeated " dressings of ammonium sulphate, calcium nitrate and urea, in which the same total quantity of N was divided equally between cuttings. Formalised casein produced much lower yields than these " repeated " dressings in the early

part of the season, but was of only slightly less value at the last cut in 1956 and gave the highest yield at the final cut in 1957. Aggregate yields from repeated dressings of inorganic N fertilisers were higher than those given by single dressings of either form of casein. Urea applied before sowing (at 0·5 cwt. N/acre) affected germination and plant establishment slightly. Under dry conditions both urea and calcium nitrate gave higher yields than ammonium sulphate, but with adequate rain the three fertilisers behaved similarly.

2.17. Williams, R. J. B., Stojkovska, A., Cooke, G. W. & Widdowson, F. V. (1960). Effects of fertilisers and farmyard manure on the copper, manganese, molybdenum and zinc removed by arable crops at Rothamsted. *J. Sci. Fd Agric.* **11**, 570–575.

The Cu, Mn, Mo and Zn contents of five different crops grown in an experiment testing farmyard manure (FYM) and N, P and K fertilisers were measured. Fertilisers and FYM had similar and rather small effects on the percentages of micro-nutrients in the crops; the total amounts of micro-nutrients removed were related mainly to the yields. Clover and kale removed much more Mo than did the other crops; clover had a high requirement for all the micro-nutrients examined. The fertilisers used supplied only insignificant amounts of micro-nutrients, whereas the 15 tons/acre of FYM supplied as much Cu, Mn and Mo as the five crops together removed, and nearly as much Zn. The soil used contains enough of these micro-nutrients for very many rotations of arable crops provided the total quantities present become available. Although the FYM dressing used supplied more of each of the micro-nutrients than was needed by any of the crops grown, it affected crop growth by the N, P and K it supplied and by improving physical conditions in the soil.

Pedology Department

General Paper

3.1. Stephen, I. (1960). Clay orientation in soils. *Sci. Progr. Lond.* **48**, 322–330.

A review of recent work with 35 references. Optical anisotropy of clay aggregates in sedimentary deposits and soils results from the orientation of the individual platelets. Several distinctive patterns of clay morphology exist in undisturbed soils, and detailed investigation of the micromorphology yields valuable information on the conditions of deposition of the parent material and on the genesis of the soils, and assists in their classification.

Soil Microbiology Department

General Papers

4.1. Jackson, R. M. & Brown, M. E. (1960). Plant roots and soil micro-organisms. *Chem. & Ind.* **6**, 140–142.

4.2. Nutman, P. S. (1960). The place of the nodulated legume in agriculture. *N.A.A.S. Quart. Rev.* **49**, 20–26.

Research Papers

4.3. Brown, M. E. (1961). Stimulation of streptomycin-resistant bacteria in the rhizosphere of leguminous plants. *J. gen. Microbiol.* (In the press.)

Bacteria resistant to streptomycin and rose bengal were preferentially stimulated in the rhizospheres of several plant species. Leguminous plants were the most effective stimulants, and clover plants as young as 6 days had some effect. The separate and combined effects of rose bengal and streptomycin in the isolation medium were examined. Rose bengal alone had little effect on bacterial numbers, whereas streptomycin alone decreased them.

The two substances together affected rhizosphere counts strikingly but irregularly. The bacteria from rhizosphere and soil were grouped according to their nutritional requirements. Chromogenic bacteria with simple requirements were the most abundant resistant forms in the rhizosphere, and a species of *Flavobacterium* was especially favoured.

4.4. Gibson, A. H. & Nutman, P. S. (1961). Studies on the physiology of nodule formation. VII. A reappraisal of the effect of preplanting. *Ann. Bot.* **24**, 420–433.

The time the first nodule forms is advanced and the total number of nodules formed is depressed by growing *Trifolium pratense* L. and *Medicago sativa* L. on agar slopes previously planted with seedlings of these species. These effects were at first attributed to root secretions, which at low concentration hasten initial nodulation but at higher concentrations inhibit nodule formation. Further work has shown that initial nodulation is stimulated because the preplant removes traces of nitrate from the medium. The amount of nitrate in the tap water used to prepare the medium (6·5 p.p.m. N) increases the number of nodules formed on the control plants, and this effect explains to a considerable extent the depression of nodule numbers by preplanting. Initial nodulation was delayed by small amounts of nitrate and nitrite, but not by other forms of combined nitrogen (ammonium, asparagine and urea). All forms of combined nitrogen tested increased the number of nodules formed over a period of 8 weeks when supplied at an initial concentration of 20 p.p.m. N.

4.5. Nutman, P. S. (1961). Variation in symbiotic effectiveness in subterranean clover (*Trifolium subterraneum* L.) *Aust. J. agric. Res.* (In the press.)

The symbiotic effectiveness of 15 varieties and of four tetraploid lines in association with several strains of nodule bacteria was examined. Small differences in yield occurred between host varieties; the varietal order of response depended somewhat on the bacterial strain. Hybridisation between varieties increased yields slightly in F_2, less in F_3 and not in F_4. With one doubtful exception, all attempts to alter effectiveness by selection or breeding within hybrid material failed.

4.6. Skinner, F. A. & Walker, N. (1961). Growth of *Nitrosomonas europea* in batch and continuous culture. *Arch. Mikrobiol.* **38**, 339–349.

A clear medium was used to grow pure cultures of *Nitrosomonas europea* in flasks and in the continuous-culture apparatus.

Of several metallic ions examined in flask cultures of *Nitrosomonas*, Fe at 2 p.p.m. and Co, Mn and Zn at 1 p.p.m. were not toxic, Ni and Cr at concentrations greater than 0·25 p.p.m. inhibited growth; Cu stopped growth completely at 0·5 p.p.m. and inhibited it at 0·1 p.p.m. Stainless steel of the specification EN58B did not affect growth.

In the continuous-culture vessel *Nitrosomonas* showed a growth response to Fe only when the population exceeded about 500×10^6 organisms/ml. The minimum doubling time was about 8 hours in flasks and 11 hours in the culture vessel. With effective aeration and automatic pH control, cultures of *Nitrosomonas* were grown successfully in continuous culture, and gave a yield of 2·14 g. dry weight of bacteria from 30 litres of culture in 5 days.

Botany Department

General Papers

5.1. (Black, J. N.) & Watson, D. J. (1960). "Photosynthesis and the theory of obtaining high crop yields, by A. A. Niciporovic." An abstract with a commentary. *Field Crop Abstr.* **13**, 169–175.

5.2. Humphries, E. C. (1960). Effects of mutilation of the root on subsequent growth. *Sci. Hort.* **14**, 42–48.

Research Papers

5.3. Humphries, E. C. (1960). Inhibition of root development on petioles and hypocotyls of dwarf bean (*Phaseolus vulgaris*) by Kinetin. *Physiol. Plant.* **13**, 659–663.

Kinetin inhibits root formation on petioles and hypocotyls of dwarf bean. It induces callus on petioles but not on hypocotyls. When kinetin is subsequently withheld, normal roots originate from the callus. Kinetin counteracts the effect of naphthalene–acetic acid in inducing root formation.

5.4. Humphries, E. C. & French, S. A. W. (1960). The effect of gibberellic acid on leaf area and dry matter production in Majestic potato. *Ann. appl. Biol.* **48**, 177–188.

When gibberellic acid (50 p.p.m. in aqueous solution) was sprayed twice or six times at weekly intervals on potato plants (var. Majestic) with a low or high nitrogen supply it did not affect rate of leaf production on the main axis, but caused earlier senescence of leaves, especially with the more frequent spraying, and inhibited leaf production and growth on laterals of the high nitrogen plants at nodes 10 and 11, but not at other nodes. This central region of the stem appears to have a low growth potential, probably because it lies midway between two zones of active growth, viz., the basal branches and the younger leaves on the main stem. Competition between these is increased by gibberellic acid. Gibberellic acid increased leaf area even when lack of nitrogen was restricting growth, but this did not produce extra dry matter. Tuber weight was increased more in high nitrogen plants by two sprayings than by six sprayings. The net assimilation rate of low-nitrogen plants was halved by spraying, but was not changed in high-nitrogen plants, where the value was similar to that of low-nitrogen control plants. The high-nitrogen plants had absorbed nearly all the available nitrogen between the second and third harvests, but plants treated with gibberellic acid, nevertheless, had more total dry weight and tuber dry weight than the controls. The nitrogen content of the leaves expressed on an area basis was lower in sprayed plants and, with continued spraying, fell at the third harvest to equal that of low-nitrogen plants. Evidently, the effect of gibberellic acid depended on the interaction between the rate of application and the nitrogen supply, but further work is necessary to define the conditions that give the maximal effect on dry-matter production.

5.5. Humphries, E. C. & Maciejewska-Potapczyk, W. (1960). Effects of indoleacetic acid, naphthalene–acetic acid, and kinetin on phosphorus fractions in hypocotyls of dwarf bean (*Phaseolus vulgaris*). *Ann. Bot. Lond. N.S.* **24**, 311–316.

Total phosphorus and orthophosphate in hypocotyls of dwarf bean were increased by NAA and unaffected by kinetin. Acid-soluble bound P, representing several different compounds, was increased by NAA and by higher concentrations of kinetin. Ribonucleic acid phosphorus was greatly increased by NAA alone and slightly inhibited by kinetin (1 mg./l.). The large effect of NAA is probably associated with increased cell number.

Kinetin strongly inhibited formation of roots in bean hypocotyls, apparently not by inhibiting cell division, but by influencing the kind of cell produced.

5.6. Thorne, G. N. (1960). Variations with age in net assimilation rate and other growth attributes of sugar-beet, potato and barley in a controlled environment. *Ann. Bot. Lond. N.S.* **24**, 356–371.

When sugar beet, potato and barley plants were grown in a controlled environment, net assimilation rate based on leaf area of all species fell approximately linearly with time by 4% of the initial value per week for sugar beet, and by 15% per week for potato and barley. Net assimilation rate based on leaf weight and leaf nitrogen content decreased at about 15% of the initial

value per week for all species. Mean values for potato and barley were similar and less than for sugar beet.

Relative growth rate, relative leaf growth rate and leaf-area ratio fell with time at similar rates for all species.

5.7. Thorne, G. N. (1961). Effects of age and environment on net assimilation rate of barley. *Ann. Bot. Lond. N.S.* **25**, 29–38.

Net assimilation rate (E) of barley grown in pots in the open at Ottawa decreased during June and July by 77%, and that of similar plants transferred to a constant environment for the 2 weeks during which E was determined decreased by 90%. Thus, the fall in E with age was partially masked outdoors by the improvement of environmental conditions during the experiment. Plants grown continuously in the constant environment had lower E, greater leaf area and dry weight and earlier ear emergence than plants of similar age transferred to the constant-environment rooms from outdoors.

5.8. Thurston, J. M. (1961). The effect of depth of burying and frequency of cultivation on survival and germination of seeds of wild oats (*Avena fatua* L. and *Avena ludoviciana* Dur). *Weed Res.* **1**, 19–31.

Seeds of *A. fatua* and *A. ludoviciana* were sown in small field-plots at Rothamsted and subjected to 5 different regimes of depth and frequency of cultivation for 3 years, after which all plots were dug to 15 cm. in spring and autumn for the next 4 years.

Seed survival and germination were influenced more by species than by cultivations. The maximum survival was 61 months for *A. fatua* and 33 months for *A. ludoviciana*. *A. fatua* germinated in spring and autumn, *A. ludoviciana* in winter. Most seedlings of *A. fatua* appeared in the second spring, but 80% of seedlings of *A. ludoviciana* came in the first autumn and winter. Less than 20% of the seeds sown produced seedlings, although viability remained good throughout 8 years' dry storage. Seeds of *A. fatua* survived slightly longer at 15 cm. than in the top 5 cm. of soil; *A. ludoviciana* was less affected by depth of burying.

5.9. Wheeler, A. W. (1960). Changes in a leaf-growth substance in cotyledons and primary leaves during the growth of dwarf bean seedlings. *J. exp. Bot.* **11**, 217–226.

A leaf-growth substance, active in the etiolated dwarf French bean leaf disk test and with the same R_f value as gibberellic acid on chromatograms run with isopropanol–ammonia–water, was found in the acidic fraction of ethyl acetate extracts from dwarf French bean (*Phaseolus vulgaris*) primary leaves and cotyledons. The amount of this leaf-growth substance per cotyledon or primary leaf reached a maximum then fell; the maximum content in the primary leaves occurred later than in the cotyledons, and coincided with the maximum growth rate of the primary leaves. Leaf-growth substances did not accumulate in primary leaves of dark-grown plants.

Biochemistry Department

General Papers

6.1. Pirie, N. W. (1960). New foods for world needs. *Roy. Soc. Health J.* **80**, 198–203.

6.2. Pirie, N. W. (1960). New sources of food. *Discovery*, **21**, 374–379.

6.3. Pirie, N. W. (1960). Water hyacinth: a curse or a crop? *Nature, Lond.* **185**, 116.

6.4. Pirie, N. W. (1960). Lung cancer and tobacco mosaic virus. *Lancet*, 26 March 1960, 707.

6.5. Pirie, N. W. (1960). The present position and future needs of research on leaf protein. *Proc. Conf. on Protein Needs, Washington DC Nat. Acad. Sci.-Nat. Res. Council*, 21–32. (In the press.)

6.6. Pirie, N. W. (1961). The maintenance of life in space ships: synthesis recycling, and the steps towards a microcosm. *In: The Biology of space travel* (Inst. Biol.). (In the press.)

6.7. Pirie, N. W. (1961). Protein foods from plants. *Span*, **4**, 21–23; *Sci. World*, **5**, 20–22.

6.8. Pirie, N. W. (1961). A biochemical approach to world nutrition. *May & Baker Lab. Bull.* (In the press.)

6.9. Pirie, N. W. (1961). The production and use of leaf protein as a human food. *Far East Trade*, **16**, 310–311.

Research Papers

6.10. Byers, M. (1961). Extraction of protein from the leaves of some plants growing in Ghana. *J. Sci. Fd Agric.* **12**, 20–30.

Extracts were made from the fresh leaves of 60 tropical species by mincing them and squeezing the resultant pulp through cotton cloth. Total-N and protein-N determinations were made on the extracted juice, and the percentages of total-N and protein-N extracted, and total-N remaining in the fibre were calculated. Small samples of crude protein were precipitated from the sap at 80° and analysed for total N.

The results are classified according to the extractability of protein-N from the leaf and to the protein content of the product isolated. The legumes, most of which were specially grown, were the best sources of easily extractable and good-quality protein, but good results were also obtained with a few of the more common weeds, which in general yielded more protein than the leaves from existing crops. Leaves of some species contained much mucilage or fibre, and it was difficult to make adequate extracts from them by the method described.

6.11. Davys, M. N. G. & Pirie, N. W. (1960). Protein from leaves by bulk extraction. *Engineering*, **190**, 274–275.

The principles governing pulping and pressing moist fibrous material such as fresh leaves are set out, and descriptions are given of the pulper and press now in use.

6.12. Festenstein, G. N. (1961). The extraction of protein from green leaves. *J. Sci. Fd Agric.* (In the press.)

Extraction of nitrogenous material (especially protein nitrogen) from leaves of different species has been studied using the Pirie steel press, which grinds small quantities of leaves by forcing them through a narrow slot. Extraction of young tobacco leaves is comparable with high-speed maceration, and sedimentable material is more dispersed; extraction under alkaline conditions is increased because chloroplasts are more dispersed. 90–95% of nitrogenous material is extracted after using detergents to release nitrogen from residual fibre after initial extraction in the press; less nitrogen is released from macerated fibre.

6.13. Holden, M. (1961). The breakdown of chlorophyll by chlorophyllase. *Biochem. J.* **78**, 359–364.

1. Soluble chlorophyllase preparations were made from sugar-beet leaves, which have the highest activity of all species tested.

2. For the partly purified enzyme the optimum conditions for enzyme action are pH 7·7 at 25° and an acetone concentration of 40%.

3. When dark-grown pea seedlings with very low chlorophyllase activity were transferred to daylight the activity rose in 48 hours to a level comparable with that of light-grown seedlings.

6.14. Mann, P. J. G. (1961). Further purification and properties of the amine oxidase of pea seedlings. *Biochem. J.* (In the press.)

Preparations of pea-seedling amine oxidase, obtained by a method previously described, were further purified by column chromatography on hydroxyapatite and DEA-cellulose to give an 880-fold purification. The final preparations were pink solutions with maximum absorption at 500 mμ. This was the only band detected in the visible part of the spectrum. The colour was discharged by sodium dithionite and by 1:4-diaminobutane, under anaerobic conditions and restored by oxygenation. The colour was also discharged by hydrazine; this reaction was not reversed by oxygenation. The preparations contained 0·08–0·09% of copper. It is suggested that the pink colour comes from a copper complex of a carbonyl compound and that this complex forms the prosthetic group of the enzyme and undergoes a cycle of reduction and re-oxidation during the catalytic activity.

6.15. Mann, P. J. G. (1960). Further purification and properties of the amine oxidase of pea seedlings. *Biochem. J.* **76**, 44 P.

6.16. Morrison, J. E. & Pirie, N. W. (1961). The large-scale production of protein from leaf extracts. *J. Sci. Fd Agric.* **12**, 1–5.

Juice from fresh, pulped leaves is freed from most of the starch grains, fibre and detritus and coagulated quickly with steam. The protein coagulum is filtered off, washed with water at pH 4 and pressed into blocks with 30–40% dry matter. In this form it keeps under refrigeration.

Texture, colour and nutritive value of the final product are determined by the conditions of drying. The precautions needed during drying, especially freeze-drying, are described. The products are fairly stable at room temperature, but lipids have to be removed before the protein will keep permanently. The conditions for doing this by acetone extraction are described.

The composition of the protein and the uses to which it can be put are described briefly.

6.17. Pirie, N. W. (1961). The disintegration of soft tissues in the absence of air. *J. agric. Engng Res.* (In the press.)

A device is described in which, with exclusion of air, soft materials are pulped by being forced through a slot of adjustable width at high pressures.

6.18. Singh, N. (1960). Differences in the nature of nitrogen precipitated by different methods from wheat leaf extracts. *Biochim. biophys. Acta*, **45**, 422–428.

More nitrogen is always precipitated from a leaf extract by trichloroacetic acid than by boiling the extract. When the extract is coagulated by slow heat much nucleic acid is lost, probably from the activity of leaf RNase during heating. If the coagulation is done by rapid heating the enzymes are inactivated, but some nucleic acid remains uncoagulated due to partial disruption of nucleo-proteins. Trichloro-acetic and perchloric acids behave similarly and precipitate N which consists of protein N as well as nucleic acid N. Uranyl TCA precipitates some TCA soluble polynucleotides and also renders some lipoprotein–polynucleotide complex insoluble in fat solvents.

Plant Pathology Department

General Papers

7.1. Bawden, F. C. (1960). Plant viruses: what they are and what they do. *Proc. roy. Instn G.B.* **38**, 50–69.

7.2. Bawden, F. C. (1960). Plant diseases. *Bull. atom. Scient.* **16**, 247–250.

7.3. Bawden, F. C. (1960). Soil-borne viruses. *Agriculture, Lond.* **67**, 387–391.

7.4. GLYNNE, MARY D. (1960). Eyespot and take-all of wheat and barley. *In: New techniques in the development of winter wheat.* Nickersons, Grimsby.

7.5. GREGORY, P. H. (1960). Outdoor aerobiology. *Endeavour*, **19**, 223–228.

7.6. GREGORY, P. H. (1960). Botrytis diseases of narcissus. *Daffodil Tulip Yearb. for* **1961**, 112–116.

7.7. HARRISON, B. D. (1960). The biology of soil-borne plant viruses. *Advanc. Virus Res.* **7**, 129–159.

7.8. KLECZKOWSKI, A. (1960). Photoreactivation in viruses and plants. *3rd int. Congr. Photobiol.*, Copenhagen, 1960.

7.9. LAPWOOD, D. H. (1960). Recent developments in breeding for the control of potato blight. *N.A.A.S. Quart Rev.* no. **47**, Spring 1960, 93–98.

7.10. WATSON, MARION A. (1960). Interaction, or genetic recombination, between potato viruses Y and C. *In:* Symposium on " The nature and exploitation of crop plants; resistance to disease ". London, January 1960.

7.11. WATSON, MARION A. (1960). The ways in which plant viruses are transmitted by vectors. *Rep. 7th Commonwealth ent. Conf.* London, 1960.

RESEARCH PAPERS

7.12. BAWDEN, F. C. & KLECZKOWSKI, A. (1960). Some effects of ultraviolet radiation on the infection of *Nicotiana glutinosa* leaves by tobacco mosaic virus. *Virology*, **10**, 163–181.

Ultraviolet radiation affects the capacity of *Nicotiana glutinosa* leaves to support the multiplication of tobacco mosaic virus (TMV) more than was assumed by previous workers, and conclusions drawn from experiments in which leaves were irradiated at different intervals after inoculation are of doubtful validity. The effects vary greatly with changes in the physiological state of leaves, and, although exposing irradiated leaves to daylight can repair irradiation damage, photoreactivation does not produce a constant response; depending on the dose of radiation energy and the state of the leaves, photoreactivation may enhance the original capacity, restore it completely or restore it only partially. Rubbing leaves twice can prevent daylight from repairing damage done by radiation to the leaf's capacity.

The response to photoreactivation also depends on the type of inoculum. When leaves are inoculated with intact TMV immediately after irradiation, exposure to daylight increases the number of lesions to the same extent as when irradiated leaves are kept in daylight for some hours before they are inoculated. By contrast, leaves inoculated with infective nucleic acid immediately after irradiation produce no more lesions when kept in the light than when kept in the dark; irradiated leaves kept in the light for some hours before inoculation, however, produce more lesions than comparable leaves kept in darkness. Photoreactivation of the leaf's capacity to support infection takes some time, and it seems that the intact virus particles can survive this time unharmed *in vivo*, whereas the unstable nucleic acid is inactivated. Further evidence for the instability of the nucleic acid came from experiments with irradiated inocula; the nucleic acid was photoreactivated when leaves were exposed to daylight immediately after inoculation, but not when they were kept in darkness for 0·5–1 hour before being exposed to light. Nucleic acid that does not establish infection within an hour of inoculation seems to be destroyed.

7.13. Broadbent, L. (1960). Infectivity of aphids bred on virus-infected cauliflower plants. *Ann. appl. Biol.* **48**, 377–383.

Caged cauliflower plants infected with either cabbage black ring spot virus (CBRSV) or cauliflower mosaic virus (CIMV) were colonised with *Myzus persicae* or *Brevicoryne brassicae*. Winged and wingless aphids that voluntarily flew or walked from these plants were transferred singly to healthy cauliflower or other brassica seedlings to compare their feeding behaviour and ability to transmit the viruses. Wingless aphids settled to probe more readily than winged, and *B. brassicae* was initially more restless than *M. persicae*. CIMV was more readily transmitted than CBRSV by both species, and *B. brassicae* rarely transmitted CBRSV. Wingless aphids transmitted less often than winged ones, and no wingless *B. brassicae* transmitted CBRSV, although they did CIMV. Fewer aphids transmitted CBRSV from old plants than from young ones, but plant age had little effect on CIMV transmission.

7.14. Broadbent, L. & Heathcote, G. D. (1960). Detection of leaf roll in potato tubers. *Plant Path.* **9**.

Some potato plants show no external symptoms during the year in which they become infected with virus. As their tubers will give diseased plants in the next year, a method for deciding whether or not seed tubers are infected would be very useful. Two methods were tested. First, a staining technique was tried, based on the abnormal formation of callose in the phloem sieve tubes of tubers with leaf-roll virus. Second, newly harvested tubers were treated chemically to break their dormancy, and they were grown on the south coast of England during the autumn.

The staining technique was unsatisfactory because only leaf roll is identified and virus Y is often prevalent in some parts of England. The second method shows little promise because of the danger of frost and the slight symptoms shown in the autumn.

7.15. Broadbent, L., Heathcote, G. D., (Brown, P. H. & Wheeler, G. F.) (1960). Home produced seed potatoes (earlies). 1. Prevention of virus infection by spraying for aphid control. *Exper. Hort.* **3**.

Trials at Efford Experimental Horticulture Station showed that whereas unsprayed stocks of first early potatoes quickly became infected with aphid-transmitted viruses, particularly leaf roll, spraying controlled aphids and limited the spread of viruses *within* the crop. Sprayed stock were retained healthy enough to use as seed for several years. Roguing in addition to spraying further decreased incidence. The thoroughness and correct timing of spraying was important. It should begin at 75% emergence and be repeated at 14-day intervals as long as the plants are actively growing. DDT emulsion is an efficient and economic insecticide used at 2 lb. active ingredient per acre per application.

7.16. Broadbent, L., Heathcote, G. D. & Burt, P. E. (1960). Field trials on the retention of potato stocks in England. *Eur. Potato J.* **3**, 251–262.

Field trials done to supplement replicated small-plot trials showed that the incidence of leaf roll and Y viruses in potato crops remained low for several years in many parts of England when the crops were sprayed with insecticide, and in some parts, where aphids were few, without spraying. Four sprays with DDT emulsion at 2 lb. of active ingredient per acre per application, at intervals of 14 days, starting soon after the plants emerged, were enough to check spread from sources within the crop.

Insecticides did not prevent viruliferous aphids, coming from outside the crop, from infecting sprayed plants. Although many growers could safely keep potato stocks for several years longer than they do now, others could not because virus Y is introduced by aphids from other crops in the same area. Risk from incoming infective aphids will remain until all potato crops are free from virus, but if all infected crops were sprayed with an efficient aphicide before the summer dispersal flight this should greatly decrease the amount of disease introduced into healthy crops.

7.17. Burt, P. E., Broadbent, L. & Heathcote, G. D. (1960). The use of soil insecticides to control potato aphids and virus diseases. *Ann. appl. Biol.* **48**, 580–590.

(For summary see below no. 9.5.)

7.18. Buxton, E. W. (1960). Effects of pea root exudate on the antagonism of some rhizosphere micro-organisms towards *Fusarium oxysporum* f. *pisi*. *J. gen. Microbiol.* **22**, 678–689.

The microbial populations of rhizosphere soil from pea varieties Onward, susceptible to wilt by *Fusarium oxysporum* f. *pisi* race 1, and wilt-resistant Alaska were assessed at six successive plant-growth stages, by the dilution plate technique. The most commonly found rhizosphere organisms were: *Gliocladium roseum*, *Penicillium* spp., bacteria, *Fusarium roseum*, *F. oxysporum*, *F. solani*, *Mortierella* spp., *Rhizopus stolonifer* and *Trichoderma viride*. Root exudate from variety Onward stimulated growth and sporulation of some of the more prevalent 24 of 60 different species among 137 morphologically different isolates of fungi and bacteria. Testing the rhizosphere isolates for their *in vitro* effects on the pathogenic *Fusarium* showed that 15% had no effect, 29% were slightly inhibitory, 42% considerably more and 14% strongly inhibitory. Prominent among the strongest inhibitors were a few bacteria, *Gliocladium roseum* and strains of *F. oxysporum*, the last showing that intra-specific inhibition occurs among the Fusaria.

When 10 of the more prevalent rhizosphere fungi were grown in media containing rhizosphere soil extract, root exudate or both, their ability to inhibit the pathogenic *Fusarium* greatly increased; the most inhibition was obtained with culture filtrates of fungi grown in the presence of both rhizosphere soil extract and root exudate. Morphologically different isolates of *Gliocladium roseum* and *Fusarium oxysporum* inhibited the pathogenic *Fusarium* to different extents, showing that these species contain physiologic strains that could act differentially towards *F. oxysporum* f. *pisi* in the rhizosphere.

The rhizosphere of the wilt-resistant variety Alaska contained no more inhibitory isolates than the rhizosphere of the wilt-susceptible Onward. Although there were more micro-organisms per unit of dry rhizosphere soil of the susceptible variety, the species isolated from the rhizospheres of the susceptible and resistant varieties did not differ qualitatively.

Rhizosphere micro-organisms that were more prevalent up to the time that *Fusarium* invaded the host roots were not prominent among the group most antagonistic towards the *Fusarium*. In addition, there was no correlation between stimulation of rhizosphere organisms by root exudate and their antagonism towards the *Fusarium*. This implies that competition between pathogenic *Fusarium* and the other rhizosphere micro-flora for nutrients in root exudates may be at least as important as overcoming antibiosis in maintaining successful growth of the pathogen near host-root surfaces. Although these results are obtained *in vitro*, they suggest that rhizosphere soil extract and microbial metabolites together deter the growth of *Fusarium oxysporum* f. *pisi* near pea roots, and that the growth-promoting effects of root exudate from the wilt-susceptible pea variety Onward are partially offset by its ability to increase inhibition by some of the other rhizosphere inhabitants.

7.19. Buxton, E. W., (Doling, D. A.) & (J. D. Reynolds) (1960). Additional pea varieties and new selections resistant to Fusarium wilt. *Plant Path.* **9**, 54–56.

During 1959 further experiments to find pea varieties that resisted wilt, caused by *Fusarium oxysporum* f. *pisi*, were done in the same way as those in 1958 and earlier (Buxton, Perry, Doling & Reynolds, *Plant Path.* 1959, **8**, 39–45). Two approaches to the problem were made: testing for wilt-resistance in progeny of healthy plants selected from varieties that wilted in 1958, and growing further pea varieties to determine their reactions to wilt. The experiments were at Yaxley, Peterborough, on wilt-infested land used for the 1958 experiments, and at Coggeshall, Essex, on a field that had carried severely wilted crops of peas, varieties British Lion and Clipper, in 1958.

7.20. (Cadman, C. H.,) Dias, H. F. & Harrison, B. D. (1960). Sap-transmissible viruses associated with diseases of grape vines in Europe and North America. *Nature, Lond.* **187**, 577–579.

Viruses were transmitted to *Chenopodium amaranticolor*, *Nicotiana clevelandii* and other herbaceous plants by inoculation of sap from North American, Portuguese, French and Swiss grape vines affected by virus diseases of either the fanleaf type or the yellow mosaic type, but not from normal grape vines of the same varieties. An isolate from a North American grape vine with fanleaf caused typical fanleaf symptoms when transmitted back to grape, but it is uncertain whether the viruses obtained from plants with diseases of the yellow mosaic type are the cause of the yellow mosaic symptoms. Isolates from grape plants with yellow mosaic diseases were less virulent in herbaceous plants than those from plants with fanleaf-type symptoms. *In vitro* properties in *C. amaranticolor* sap of five isolates selected for detailed study were: thermal inactivation point, 58–65°; dilution end-point, $\frac{1}{500}$–$\frac{1}{10000}$; longevity *in vitro* at 18°, 6–28 days. Serological tests showed that all the isolates tested had antigens in common and polygonal particles of diameter about 30 mμ. The grape viruses also share a few of their antigens with arabis mosaic virus. The distribution of a disease of the fanleaf type in two Portuguese vineyards was correlated with that of the nematode *Xiphinema index*, whereas *X. americanum* was present in all parts of the vineyards.

7.21. Gibbs, A. J. (1960). Studies on the importance of wild beet as a source of pathogens for the sugar-beet crop. *Ann. appl. Biol.* **48**, 771–779.

Beet yellows virus, beet mosaic virus, rust (*Uromyces betae* (Pers.) Lév.) and downy mildew (*Peronospora schachtii* Fuckel) were found to be common in wild beet (*Beta vulgaris* S.-sp. *maritima* L.) growing on the foreshores of South Wales and southern England. The virus diseases were more prevalent in south-east England than in the west, rust more in the west than in the east, and downy mildew is equally prevalent in all regions.

Beet yellows is the most commercially important disease and is more common in sugar-beet crops in East Anglia than elsewhere in Great Britain. There was no evidence that beet yellows spread in East Anglia from wild beet to nearby sugar-beet crops during the springs of 1958 or 1959, and *Myzus persicae* Sulz., the principal vector of yellows, was rarely found on wild beet growing on the foreshore.

In glasshouse experiments aphids colonised sugar-beet plants watered with tap water in preference to those watered with sea-water. Daily watering with sea-water made plants unpalatable to aphids within 14 days. Aphids also preferred leaves sprayed with distilled water to those that had been sprayed with sea-water. Salt solutions gave results similar to those obtained with sea-water.

7.22. Gibbs, A. J. & Gower, J. C. (1960). The use of a multiple-transfer method in plant virus transmission studies—some statistical points arising in the analysis of results. *Ann. appl. Biol.* **48**, 75–83.

The frequency of success of attempts to transmit a virus disease from one plant to another has long been used to measure the effects of any of the factors which influence transmission. Samples are taken from the population under test (e.g., vectors, diseased plants, etc.), and usually one sample is tested on each test plant; this is binomial sampling. However, in the procedure we name the " multiple-transfer method " more than one sample may be tested on each test plant. This increases the number of samples tested without increasing the number of test plants used, and errors from heterogeneity in the population under test are therefore lessened. Results from experiments using the multiple-transfer method may be evaluated by using the maximum likelihood estimator. The method is particularly reliable when the proportion of infected samples being studied is small, but can lead to considerable over-estimation when the proportion is high.

7.23. HARRISON, B. D. & NIXON, H. L. (1960). Purification and electron microscopy of three soil-borne plant viruses. *Virology*, **12**, 104–117.

Highly infective, purified preparations of tomato black ring, raspberry ringspot and arabis mosaic viruses were obtained by macerating infected *Petunia hybrida* or tobacco leaves in a butanol–chloroform mixture, followed by clarification, differential centrifugation and rate zonal centrifugation in sucrose density gradients. The sedimentation rates of the three viruses relative to that of tobacco mosaic virus were estimated. Electron micrographs of shadowcast mounts of formalin-treated preparations showed that all three viruses have icosahedral particles of average diameters 29–30 mμ. Particles embedded in phosphotungstate often appeared polygonal in outline, but were smaller in diameter than those in shadowed mounts. Some particles of each virus were deeply penetrated by phosphotungstate, but others were not. Infectivity was always associated with the presence of unpenetrated particles, but there was no evidence that the penetrable ones were infective. Particle shape, mode of transmission, properties *in vitro* and behaviour in plants all suggest that these viruses should be placed in the same general group in any classification of plant viruses.

7.24. HIRST, J. M. & STEDMAN, O. J. (1960). The epidemiology of *Phytophthora infestans*. I. Climate, ecoclimate and the phenology of disease outbreak. *Ann. appl. Biol.* **48**, 471–488.

Temperature and relative humidity of air within and above potato crops were recorded throughout the growing seasons of 1951–58, with wet- and dry-bulb mercury-in-steel thermographs. Diurnal periodicity curves of successive weeks showed that conditions within the crop changed, relative to those above, as the crop grew. When much bare ground was exposed the air within the crop was warmer and less humid at midday than at 4 feet above ground, particularly in dry and sunny weather. The growth of foliage and the amount of sunshine and rain determined how quickly this pattern was replaced by one with smaller temperature differences and crop humidity slightly in excess of that above it, at all times of day. Rain on crops with dense foliage almost completely eliminated temperature differences and gave relative humidities over 90% that persisted in the crop for a larger proportion of each day than in the screen. Finally, as the disease defoliated the crop and again exposed the soil, the relationship partly reverted to that early in the season.

Above the crops, curves of the number of hours per day with relative humidity not less than 90% rose and fell with the passing of wet spells. At first this was also true within crops, but when foliage was dense the rise in relative humidity after rain often persisted through intervals of dry weather. Such conditions usually preceded the appearance of potato blight in epidemic proportions by 1–3 weeks. It is difficult to account for the regularity of blight outbreaks by seasonal climatic changes, and although many factors are probably involved, changes in ecoclimate seem important. When knowledge about the response of *Phytophthora infestans* is related to the meteorological observations and to the dates of blight outbreak the growth of potato crops seems often to be self-destructive, because it progressively modifies the immediate environment to favour the spread of the crop's most destructive pathogen.

7.25. HIRST, J. M. & STEDMAN, O. J. (1960). The epidemiology of *Phytophthora infestans*. II. The source of inoculum. *Ann. appl. Biol.* **48**, 489–517.

Of 3,260 blighted tubers planted as seed in 5 successive years (1954–58), 21 produced stems invaded from below ground by *Phytophthora infestans* (0·79 and 0·52% respectively of those infected artificially and naturally). Only in 1955 was no stem found to be invaded, in every other year they started epidemics in experimental plots. On average, the first stem lesions were found 62 days after planting and 38 days before blight outbreak became general in the district.

There was evidence of two patterns of dispersal for *P. infestans*. Distant spread was probably by air-borne sporangia, but that near to the initial sources probably resulted from sporangia transported in water. The effects of initial

sources of infection on the date when the disease became general could not be traced for more than a few hundred yards. Blight often reached crops remote from the experiments at the same time as it infected every plant within them; this often happened during the weather which elicited disease forecasts.

Under certain conditions of soil moisture *P. infestans* from artificially infected tubers planted as seed seemed able to pass through the soil to infect leaves near it and to start epidemics without invading stems from below ground. Attacks originating in this way developed similarly to those started by invaded stems, but their importance and the conditions limiting their occurrence have yet to be determined.

7.26. KASSANIS, B. (1959). Comparison of the early stages of infection by tobacco mosaic virus and its nucleic acid. *J. gen. Microbiol.* **20**, 704–711.

The early events in the infection of tobacco and *Nicotiana glutinosa* by tobacco mosaic virus occur sooner when the inoculum is the nucleic acid of the virus than the whole virus. In plants at 28° newly formed virus becomes detectable between 6 and 8 hours after inoculation with the nucleic acid and after 8–10 hours with whole virus. Although the latent period is lengthened by lowering temperature, the difference between the lengths of the latent periods given by the two inocula is little changed. Infective centres initiated by nucleic acid also become resistant to hot-water treatment (a 30-second dip in water at 50°) about 2–4 hours sooner than do those initiated by whole virus.

Exposure of inoculated plants to 37° decreases the number of lesions produced by the nucleic acid much more than by whole virus; resistance to this treatment develops from 30 to 120 minutes after inoculation with the nucleic acid, depending on the temperature at which the plants are kept.

7.27. KASSANIS, B. (1960). Potato virus M and paracrinkle. *Nature, Lond.* **188**, 688.

A short account is given of the different strains of potato paracrinkle virus found in commercial stocks of the potato variety King Edward; some of the strains are transmitted by aphids.

7.28. KASSANIS, B. & NIXON, H. L. (1960). Activation of one plant virus by another. *Nature, Lond.* **187**, 713–714.

This is a preliminary note on the relationship between the small and large virus particles present in the " Rothamsted culture " of tobacco necrosis virus.

7.29. MULLIGAN, T. E. (1960). The transmission by mites, host-range and properties of ryegrass mosaic virus. *Ann. appl. Biol.* **48**, 575–579.

A virus that causes chlorotic streaks on ryegrass leaves was transmitted by the eriophyid mite *Abacarus hystrix* (Nalepa). Virus-free mites acquired the virus in 2 hours feeding on infected ryegrass, and the proportion that became infective increased with increased feeding time up to 12 hours; vectors lost infectivity within 24 hours of leaving the infected leaves. All instars of *A. hystrix* transmitted the virus.

The virus was transmitted by manual inoculation of sap to other species of Gramineae, including oats, rice, cocksfoot and meadow fescue, but none of these hosts seemed to contain as much virus as ryegrass; their saps did not precipitate specifically with antiserum prepared against the virus in ryegrass, whereas sap from infected ryegrass precipitated up to a dilution of $\frac{1}{32}$. Infective sap of S.22 Italian ryegrass contained flexuous rod-shaped particles; the dilution end-point of the virus was about 1 in 1000; the virus was inactivated when held for 10 minutes at 60° and most of its infectivity was lost after 24 hours at room temperature.

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7.30. Nixon, H. L. & Gibbs, A. J. (1960). Electron microscope observations on the structure of turnip yellow mosaic virus. *J. molec. Biol.* **2**, 197–200.

Electron micrographs of turnip yellow mosaic virus particles prepared by the negative staining technique show clearly defined internal structure which indicates that the protein shell of this virus is constructed of 32 sub-units in an icosahedral arrangement. The structure inferred from the electron micrographs satisfies the X-ray data and contains sub-units in two structurally distinct sites.

7.31. Sinha, R. C. (1960). Comparison of the ability of nymph and adult *Delphacodes pellucida* Fabricius, to transmit European wheat striate mosaic virus. *Virology*, **10**, 344–352.

The ability of *Delphacodes pellucida* Fabricius to transmit European wheat striate mosaic virus to progeny insects and to plants depends on the age at which they acquire virus from diseased plants, and is greater with nymphs than with adults. Infective progeny and eggs that died were produced only by infective mothers that had fed on diseased plants when nymphs. There may be a critical time comparatively early in the development of the ovaries before which the virus must be established in them to be transmitted to progeny insects.

Adult plant-hoppers were rendered infective by puncturing their anterior abdomens with a fine needle immediately before or after feeding on diseased plants. Puncturing the abdomen a week after acquiring the virus or puncturing the thorax at any time did not make them infective. Evidently wheat striate mosaic virus must pass through the gut wall of *D. pellucida* for the insect to become infective, and the permeability of the gut wall to virus presumably decreases with increasing age of insect.

7.32. Sinha, R. C. (1960). Red clover mottle virus. *Ann. appl. Biol.* **48**, 742–748.

A virus, provisionally named red clover mottle virus (RCMV), isolated from red clover plants in England seems distinct from any previously described. It was transmitted by mechanical inoculation of sap to many legumes and to *Gomphrena globosa* L., but it was not transmitted by six aphid species, through soil or through seeds.

RCMV is inactivated in 10 minutes between 60 and 63°, and in 8 days at 18°, but survives for long periods at −20°; sap was not infective when diluted more than $\frac{1}{1000}$. The virus is soluble in the pH range (4–7), in which it is stable. It was precipitated without inactivation by 50% saturated ammonium sulphate solution, but it was inactivated by ethanol or acetone. Partially purified preparations contained polygonal particles about 28 mμ in diameter. Serological tests showed no antigens in common with broad bean mottle, true broad bean mosaic or lucerne mosaic viruses.

7.33. Sinha, R. C. (1960). Some effects of temperature and of virus inhibitors on infection of French-bean leaves by red clover mottle virus. *Ann. appl. Biol.* **48**, 749–755.

Keeping French-bean plants before inoculation at 36°, 32° or 28° for 1–2 days increased their susceptibility to infection with red clover mottle virus, but longer exposures to 36° and 32° decreased susceptibility. Susceptibility increased most rapidly at 36°. The number of infections was unaffected by changes in post-inoculation temperatures between 12° and 24°, but decreased above 24°. The rate virus multiplied increased with increase of temperature up to 28°, but the maximum virus concentrations reached at 18°, 24° and 28° were very similar and above the maximum reached at 30°.

Thiouracil inhibited infection slightly, but neither it nor azaguanine affected the multiplication of red clover mottle virus in French bean. Trichothecin inhibited infection and interfered with virus accumulation. Inhibition of infection was associated with macroscopic injury to the leaves, and washing leaves up to 1 hour after inoculation prevented both inhibition and leaf damage. Virus multiplication was not resumed when leaves were transferred from trichothecin solutions to water.

7.34. WATSON, M. A. (1960). Evidence for interaction or genetic recombination between potato viruses Y and C in infected plants. *Virology*, **10**, 211–232.

When potato virus Y (PVY), which is aphid-transmitted, and a related virus, potato virus C (PVC), which is not aphid-transmitted, were jointly inoculated to *Nicotiana glutinosa* plants, mixed isolates, transmitted by aphids from systemically infected leaves had some of the properties of both.

Like PVY, they were transmitted by *Myzus persicae*, but unlike PVY, they caused black necrotic lesions on inoculated leaves of Majestic, President and Craig's Snow-White potatoes (*Solanum tuberosum* L.). Like PVY and unlike PVC, they caused systemic infection when manually inoculated to the potato varieties, but the symptoms that developed resembled those caused by PVC when it is transmitted to the same varieties by grafting. Many isolates from local lesions caused by the mixed virus isolates on potato were like PVC, and few resembled PVY. Isolates from systemically infected parts of potato less often gave symptoms like those caused by PVC, and many gave mild mottle with no necrosis.

Three PVC-like viruses that resemble the isolates from mixed infection are: PVC^{a}, and aphid-transmissible PVC-like virus described previously (Watson, 1956); PVC^{niab}, found naturally occurring in International Kidney potatoes in Jersey, and a virus from India found in *Solanum jasminoides* (Badami and Kassanis, 1959). These viruses do not usually invade the potato varieties systemically, but occasionally yield isolates that do so. The symptoms when they do invade resemble those caused by the isolates from mixed infections in *N. glutinosa*, and often appear to be genetically unstable, although the viruses from which they were derived are either stable in potato or, as with PVC^{a}, revert to a form even more like PVC.

The nature of the interaction between PVC and PVY is unknown, but a likely explanation is that particles are formed that carry genetic determinants from both viruses.

7.35. WATSON, M. A. (1960). Carrot motley dwarf virus. *Plant Path.* **9**, 133-134.

A virus disease of carrots that causes loss of yield in commercial crops is probably carrot motley dwarf described from Australia by Stubbs (1948, 1952). The vector is the willow-carrot aphid *Cavariella aegopodiae*, which migrates in great numbers during May or June. Carrot motley dwarf is a persistent virus, the aphids take several hours to acquire and transmit it, but remain infective for many days. In 1959 carrots at Woburn, Beds, were almost 100% infected before the end of May.

7.36. WATSON, M. A. & MULLIGAN, T. (1960). Comparison of two barley yellow-dwarf viruses in glasshouse and field experiments. *Ann. appl. Biol.* **48**, 559–574.

Comparisons were made of the host ranges, interactions in infected plants and effects on yields of cereals of two isolates of barley yellow-dwarf virus, one avirulent, RV, obtained from Rothamsted farm, and the other virulent, KV, obtained from Kent. They resembled each other and the American yellow-dwarf viruses in their ability to infect wild grasses, but differences were found when the infection tests were made using inbred lines of the same grass species. KV infected one variety each of rice, rye and maize, and caused symptoms in each.

When plants were first infected with RV and later, when symptoms had fully developed, with KV, they suffered the same loss of yield from KV as did plants infected for the same length of time with KV alone. Therefore plants infected with RV were not protected against infection with KV. Similarly, aphids (*Rhopalosiphum padi* L.) fed first on sources of RV and then on KV, transmitted mainly KV, so there was no evidence of protection in the insect vectors.

Effects on yield of cereals were related to the time of appearance and intensity of symptoms. The effect of RV was less than that of KV and varied more.

7.37. Watson, M. A. & Mulligan, T. (1960). The manner of transmission of some barley yellow-dwarf viruses by different aphid species. *Ann. appl. Biol.* **48**, 711–720.

Some barley yellow dwarf (BYD) viruses isolated from cereal crops in Great Britain were transmitted by *Rhopalosiphum padi* L. and others were not. *Sitobium fragariae* (Walker), *S. avenae* (Fabricius) and *Metopolophium dirhodum* (Walker) all transmitted viruses of both types, but they usually transmitted those of which *R. padi* was a vector less readily than did *R. padi*. The transmissibility of a virus by a given aphid species was not affected by transmission with another, less efficient, vector species. *Myzus circumflexus* (Buckt.) and *Rhopalosiphum maidis* (Fitch) transmitted the few viruses with which they were tested.

A few *R. padi* acquired virus from infected leaves during 30 minutes feeding and inoculated healthy seedlings during 15 minutes feeding, but the minimum total time taken to acquire and transmit was 10 hours, and 32 hours were needed for about half the aphids that were able to acquire and transmit virus to do so. This may indicate the existence of a short latent period of the virus in the vector, although the evidence is not conclusive. The times spent on infected plants influenced the results more than those spent on healthy ones; many transmissions occurred with short feeding times on healthy plants so long as the time spent on infected leaves was long, but the reverse was not true. Nymphs of *R. padi* that moulted after they left infected plants on which they fed long enough to become infective, infected slightly fewer plants than adults fed for the same times.

Nematology Department

General Papers

8.1. Goodey, J. B. (1960). Gall-forming nematodes of grasses in Britain. *J. Sports Turf Res. Inst.* **10**, 54–60.

8.2. Hesling, J. J. (1961). Laboratory note. *Nematologica*, **5**, 322.

8.3. Hesling, J. J. (1961). Chrysanthemum eelworm. *Gdnrs' Chron.* **149**. (In the press.)

8.4. Jones, F. G. W. (1959). Resistance breaking biotypes of potato-root eelworm. *Proc. IVth int. Congr. Crop Protection Hamburg 1957*, **1**, 591–594.

8.5. Jones, F. G. W. (1960). Plant parasitic nematodes. *Advanc. Sci.* **17**, 174–180.

8.6. Jones, F. G. W. (1961). Some observations and reflections on host finding by plant nematodes. *Meded. LandbHoogesch. Gent*, **25**, 1009–1024.

8.7. Jones, F. G. W. (1960). Nematode injury to crops. *Proc. Nutr. Soc.* **20**. (In the press.)

8.8. Wallace, H. R. (1960). Recent observations on chrysanthemum eelworm. *Quart. Bull. nat. Chrysanth. Soc.* no. 43, 10–13.

8.9. Wallace, H. R. (1961). Chrysanthemum eelworm. *Year Book nat. Chrysanth. Soc.* 1960/61, 107–123.

8.10. Wallace, H. R. (1961). The bionomics of the free-living stages of zoo-parasitic and phyto-parasitic nematodes—a critical survey. *Helminth. Abstr.* **30**, 1–22.

8.11. Winslow, R. D. (1960). Nematode ecology. *In: Nematology*, ed. J. N. Sasser & W. R. Jenkins. Chapel Hill, U.S.A., Univ. N. Carolina Press, pp. 341–415.

Research Papers

8.12. Clark, W. C. (1960). The oesophago-intestinal junction in the Mononchidae (Enoplida: Nematoda). *Nematologica*, **5**, 178–183.

Some morphological features of the oesophago-intestinal junction of the Mononchidae often disappear soon after fixation, especially the funnel-shaped valve which is surrounded by the sphincter muscle. Published accounts of this region do not agree with the morphology of live nematodes. The oesophago-intestinal valves of the Mononchidae are of two types: 1. the *tuberculate* type, which is characterised by the presence of three conspicuous, hollow tubercles on the posterior end of the oesophageal lining near the funnel-shaped valve, and 2. the *non-tuberculate* type, in which the tubercles are absent and the oesophageal lining becomes narrower near the posterior end. The *tuberculate* type of valve is found in *Anatonchus*, *Iotonchus* and *Miconchus*; and the non-tuberculate type in *Mononchus*, *Prionchulus*, *Mylonchulus* and *Cobbonchus*.

Mononchus mauritianus Williams, 1958, is transferred to the genus *Cobbonchus* Andrássy.

8.13. Clark, W. C. (1960). Redescription of *Mononchus truncatus* Bastian, *M. papillatus* Bastian and *Prionchulus muscorum* (Dujardin). *Nematologica*, **5**, 184–198.

Mononchus truncatus Bastian (= *M. macrostoma* Bastian) and *M. papillatus* Bastian are redescribed from topotypic material, and neotypes have been designated. *Prionchulus muscorum* (Dujardin, 1945) Cobb, 1916, is redescribed from British populations. The differences between *M. papillatus* and *P. muscorum* are tabulated.

8.14. Clark, W. C. (1960). The Mononchidae (Enoplida: Nematoda) of New Zealand. 1. The genera *Mononchus* Bastian and *Prionchulus* (Cobb). *Nematologica*, **5**, 199–214.

Mononchus composticola, *M. mesadenus*, and *M. propapillatus* n. spp. are described, and *Prionchulus muscorum* (Dujardin) is recorded from New Zealand. *M. campbelli* Allgén, 1929, is regarded as a species *inquirenda*. *M. composticola* and *M. mesadenus* are allied to *M. gerlachei* de Man, 1904, and *M. major* Cobb, 1893, from which species they may be separated by the key provided.

8.15. Clark, W. C. (1961). The Mononchidae (Enoplida: Nematoda) of New Zealand. 2. The genus *Iotonchus* (Cobb) Altherr. *Nematologica*, **5**, 260–274.

Iotonchus (Cobb, 1916) Altherr, 1952, is redefined, and is distinguished from *Mononchus* Bastian by the tuberculate oesophago-intestinal junction, the dorsal tooth, which lies wholly or mainly in the posterior half of the stoma, and the broad base of the stoma. *I. jairi* (Lordello, 1959) n. comb. and *I. tenuidentatus* (Kreis, 1924) n. comb. are transferred to the genus from *Mononchus*.

I. basidontus n. sp. differs from *I. gymnolaimus* and *I. consimilis* in the possession of paired ovaries. *I. maragnus* n. sp. is characterised by the possession of a very long filiform tail ($c = 2{\cdot}3$–$2{\cdot}9$) and the anterior position of the vulva ($V = 36$–39). *I. ophiocercus* n. sp. is the only long-tailed member of the genus with the tooth apex near the middle of the stoma. *I. percivali* is the largest species in the genus ($L = 6$ mm.), has a long tail ($c = 3{\cdot}8$–$4{\cdot}1$), a median vulva and paired ovaries. *I. parazschokkei* (Allgén, 1929) is redescribed.

8.16. Clark, W. C. (1961). The Mononchidae (Enoplida: Nematoda) of New Zealand. 3. A review of the genus *Cobbonchus* Andrassy, with descriptions of new species. *Nematologica*, **5**, 275–284.

The genus *Cobbonchus* Andrassy, 1958, is redefined and new descriptions of *C. palustris* (Cobb), *C. radiatus* (Cobb) and *C. teres* (Cobb) have been compiled

from Cobb (1917) and some of Cobb's unpublished figures. *C. mauritianus* (Williams) has been redescribed. *C. chauliodus* n. sp. differs from others in its large size, massive dorsal tooth and single prodelphic ovary. *C. pounamua* n. sp. is distinguished from *C. palustris* on head shape, the pointed stoma base and the greater number of cephalic papillae.

8.17. Clark, W. C. (1961). The Mononchidae (Enoplida: Nematoda) of New Zealand. **4.** The genus *Mylonchulus* (Cobb) Pennak. *Nematologica*, **6**, 1–6.

Mylonchulus arenicolus and *M. ubis* n. spp. are described from New Zealand soils.

8.18. Clark, W. C. (1961). A revised classification of the Enoplida Nematoda. *N.Z. J. Sci.* **4**. (In the press.)

The order Enoplida is re-classified into seven sub-orders mainly on the basis of the arrangement of the oesophageal glands and their ducts. The sub-orders recognised are Enoplina, Alaimina n. sub-order, Dorylaimina, Trichosyringina (composed of the Mermithoidea and Trichuroidea) and Dioctophymatina. The Mononchidae are removed from the Tripyloidea, and with the Bathyodontidae n. fam. (type genus *Bathyodontus* Fielding, 1950) comprise the Mononchoidea n. superfamily within the Dorylaimina. The Belondiridae and Nygolaimidae have been redefined, *Nygellus* Thorne, 1939, is transferred from the former to the latter and the Nygolaimellinae n. subfam. (type genus *Nygolaimellus* Loos, 1949) erected. The Campydorinae are removed from the Leptonchidae and elevated to family rank. The Trichodorinae are given family rank, and with the Diphtherophoridae form the Diphtherophoroidea within the Dorylaimina. In the Trichuroidea four families and four subfamilies are recognised. Skrjabin & Schikhobalova's (1954) proposal to unite the Trichuroidea with the Dioctophymatina is rejected on the grounds of morphology and life history. The life history of *Dioctophyme renale* indicates a relationship between the Dioctophymatina and the Gordiacea. The name *Octonchus* nom. nov. is proposed pro *Polydontus* Schultz, 1932 preocc. nec. *Polydontus* Blainville, 1926, a mollusc.

8.19. Fenwick, D. W. (1961). Estimation of field populations of cyst-forming nematodes of the genus *Heterodera*. *J. Helminth.*, Leiper Supplement, 63–76.

Fields infested with cyst-forming nematodes differ greatly from one another in the level of infestation and in the uniformity of its distribution. Composite samples taken from such fields, for which general estimates of the population level are required, should be made up of from 25 to 100 borings. The increase in precision obtained by taking more than 100 borings is rarely justified. Even when more borings are taken and the quantity of soil used for extraction in the laboratory is increased to give large cyst counts, errors remain high. The accuracy of estimates based on composite samples is variable and cannot be forecast in advance for a given field. If it is desired to work at a predetermined level of accuracy preliminary samples should be taken to estimate the heterogeneity of the population. Final sampling procedure should be based on this estimate.

8.20. Franklin, M. T. (1961). A British root-knot nematode, *Meloidogyne artiellia* n. sp. *J. Helminth.*, Leiper Supplement, 85–92.

A new root-knot nematode was found by a member of the N.A.A.S. on the roots of oats and brassicas from Norfolk. This is described and named. It is the first species of *Meloidogyne* to be described initially in Britain.

8.21. Goodey, J. B. (1960). The classification of the Aphelenchoidea Fuchs, 1937. *Nematologica*, **5**, 111–126.

The Aphelenchoidea are considered to be composed as follows: Aphelenchidae—*Aphelenchus*. Aphelenchoididae—*Aphelenchoides*, *Seinura*, *Megadorus*, *Tylaphelenchus*, *Laimaphelenchus*, *Bursaphelenchus*, *Cryptaphelenchus*,

Cryptaphelenchoides, Ektaphelenchus, Parasitaphelenchus, Peraphelenchus and *Entaphelenchus*. Paraphelenchidae—*Paraphelenchus* and *Metaphelenchus*. Anomyctidae—*Anomyctus*. Sphaerulariidae—*Sphaerularia, Tripius, Proatractonema* and *Scatonema*.

8.22. Goodey, J. B. (1960). Observations on the effects of the parasitic nematodes *Ditylenchus myceliophagus, Aphelenchoides composticola* and *Paraphelenchus myceliophthorus* on the growth and cropping of mushrooms. *Ann. appl. Biol.* **48**, 655–664.

The parasitic nematodes *Ditylenchus myceliophagus, Aphelenchoides composticola* and *Paraphelenchus myceliophthorus* severely damage mushroom mycelium, and in great numbers decrease or even prevent cropping. The relationships between fluctuation of nematode population, state of the mycelium, duration of cropping and the yield of mushrooms is illustrated by figures.

8.23. Goodey, J. B. (1960). *Rhadinaphelenchus cocophilus* (Cobb, 1919) n. comb., the nematode associated with "Red-Ring" disease of coconut. *Nematologica*, **5**, 98–102.

Aphelenchoides cocophilus is placed in a new genus as *Rhadinaphelenchus cocophilus* (Cobb, 1919) n. comb. and is redescribed from fresh material. The nematode is exceedingly long and narrow ($a \simeq 100$), very lithe in water and is characterised by a flap-like terminal bursa in the male and vulval flap in the female.

8.24. Goodey, J. B. (1961). The nature of the spear guiding apparatus in Dorylaimoidea. *J. Helminth.*, Leiper supplement, 101–106.

The spear guiding apparatus is a sheath fused anteriorly and medially to the stoma wall, and basally round the junction of spear and spear extension. The fixed anterior ring is what is seen when specimens are said to have a single ring. As the spear is moved forwards the sheath evaginates, giving the appearance of an apparently double ring. These concepts are applicable to Nygolaims, where the spear is mural, and also to *Aporcelaimus*, which has a plicated, funnel-shaped anterior end to the sheath.

8.25. Goodey, J. B., Peacock, F. C. & Pitcher, R. S. (1960). A redescription of *Xiphinema diversicaudatum* (Micoletzky, 1923 and 1927) Thorne, 1939 and observations on its larval stages. *Nematologica*, **5**, 127–135.

The figures and description of *Xiphinema diversicaudatum* of Thorne (1939) appear not to agree with the originals of Micoletzky (1923 and 1927). The species is redescribed from numerous specimens which agree well with the originals. Study showed the range of variation in tail form, the number of caudal papillae, the number of subventral papillae in the male, the variation in length of the guiding sheath of the spear compared with the spear position and the range of form shown by the different larval stages.

8.26. Goodey, J. B. & Seinhorst, J. W. (1960). Further observations and comments on the identiy of *Rotylenchus robustus* (de Man, 1876) Filipjev, 1934, with a description of a proposed neotype and a new definition of *Rotylenchus goodeyi*. *Nematologica*, **5**, 136–148.

The authors do not agree with the contention of Loof and Oostenbrink (1958) that *Rotylenchus robustus* (de Man, 1876) and *Hoplolaimus uniformis* Thorne, 1949, are the same species.

Under the International Rules of Zoological Nomenclature *Tylenchus robustus* de Man, 1876, is the type of the genus *Rotylenchus* Filipjev, 1936, and Filipjev's citation of *Tylenchus robustus* de Man, 1880, has no other meaning nomenclatorially than *T. robustus* de Man, 1876.

T. robustus as described by de Man in 1876 differs in several ways (body length, spear length, form of tail and habitat) from *Hoplolaimus uniformis*, and thus is not the same species.

Several specimens have been collected from the type locality of *T. robustus* de Man, 1876 (Clayey meadow soil near Leiden), which agree closely with de Man's description of 1876 (e.g., body length, spear length and form of tail) and from these a neotype has been described.

Anguillulina robusta of T. Goodey, 1932, is considered to be the same as *Rotylenchus robustus* (de Man, 1876). *Anguillulina robusta* of T. Goodey, 1940 and 1951, is not identical with *R. robustus* (de Man), 1876, and remains *Rotylenchus goodeyi* Loof & Oostenbrink, 1958.

R. robustus of Thorne, 1949, is identical neither with *R. robustus* (de Man, 1876) nor with *R. goodeyi* Loof & Oostenbrink.

8.27. Greet, D. N. & Wallace, H. R. (1961). Diagnosis of attacks of *Aphelenchoides ritzemabosi* in chrysanthemums. *Plant Path.* **10**. (In the press.)

Leaves of some chrysanthemum varieties do not show clear interveinal discoloration. Orange Peach Blossom, Amy Shoesmith, Kathleen Doward and Delightful, for example, show interveinal symptoms only in the initial stages of infestation, the affected leaf sectors later become black with a yellow border, and the discoloration is not always limited by the veins. Only varieties resistant to eelworm behave in this manner.

8.28. Hesling, J. J. (1961). *Heterodera rostochiensis* Woll. 1923 on *Solanum demissium*—a population study. *Ann. appl. Biol.* **49**. (In the press.)

Cysts of *H. rostochiensis* in three different size grades were used at six different inoculum levels on *S. demissium*. Cyst numbers were adjusted so that the infestation levels (eggs/g. soil) were the same in each series at any one inoculum level: thus, the inoculum was dispersed within many small cysts, several medium cysts or few large ones. The different dispersions had little effect on the final eelworm population. Estimation of total egg content and hatchable, larval content of new cysts, also graded according to size, showed that neither size grade of the cysts inoculated nor the level of infestation had any effect on the egg content or hatchability of the new cysts. Percentage hatch appeared to decline with increase in cyst size; hatching variability was not usefully decreased by using graded new cysts for hatching tests. The smallest new cysts (<0·295 mm.) contained an average of 64 eggs; such cysts are easily overlooked in soil samples.

8.29. Hesling, J. J. (1961). Technical problems in the routine, hot-water treatment of chrysanthemum stools against chrysanthemum eelworm *Aphelenchoides ritzemabosi*. *Plant Path.* **10**. (In the press.)

An experimental bath was constructed for treating chrysanthemum stools in water at 46° for 5 minutes. An input power of at least 350 watts per gallon of water was required to regain a temperature drop of 0·5° in half a minute. If the ratio of stools to gallons of water exceeded 1 : 1 the temperature drop was more than 0·5°. Unless the water was circulated actively and the stools agitated during treatment there were temperature variations in the bath. Treatment of large numbers of stools on a commercial scale seems impracticable.

8.30. Hesling, J. J. & Wallace, H. R. (1961). Observations on the biology of chrysanthemum eelworm, *Aphelenchoides ritzemabosi* (Schwartz) Steiner in florists' chrysanthemum. I. Spread of eelworm infestation. *Ann. appl. Biol.* **49**, 195–203.

A study of the mobility of chrysanthemum eelworm in sand and in a clay soil indicated that it behaves like other eelworm species so far examined. The lateral spread of eelworm in chrysanthemum plots in a nursery did not exceed about 30 inches in the dry season of 1959. The number of infested plants rose sharply with the onset of damp weather in September. Laboratory

experiments showed that the eelworms were more active under humid conditions. Eelworms may invade a leaf within 15–30 minutes after their introduction to it. Eelworms inoculated into clean soil containing uninfested plants produced symptoms on the plants after 18 days, but 26 days after inoculation no eelworms could be detected in the soil. The eelworms disappear in moist fallow soil, and attempts to infest plants with eelworms from heavily infested soil stored over winter failed. Examination of stools during winter showed that many eelworms were present in the green tissues, and it was concluded that infestation from eelworms which persist in soil over winter is slight and that the main source of the pest is the chrysanthemum stool.

8.31. Hesling, J. J. & Wallace, H. R. (1961). Observations on the biology of chrysanthemum eelworm, *Aphelenchoides ritzemabosi* (Schwartz) Steiner in florists' chrysanthemum. II. Symptoms of eelworm infestation. *Ann. appl. Biol.* **49**, 204–209.

Eelworm damage to chrysanthemum leaf tissue was studied by staining leaf-sections. The earliest effect of the eelworm is the appearance of a brown substance inside the leaf-cells, the browning extends and chloroplasts become fewer. Ultimately the cell walls break down and large spaces appear in the leaf. Finally, the epidermis disintegrates and the brown substance is found on all cell walls. Collenchyma around main veins does not break down until the final stage of the disease.

Cuttings of 13 chrysanthemum varieties were artificially infested with about 110 eelworms. Ensuing symptoms were leaf blotch, stunting, blindness, browning of stem and leaf petiole, leaf distortion, leaf scars (" feeding areas ") and puffy, blistered and puckered leaves. Infested cuttings which showed severe symptoms produced side-shoots which seemed healthy, but these became badly damaged later in the season. In young leaves the eelworms were often unable to penetrate farther than the substomatal space.

8.32. Hesling, J. J. & Wallace, H. R. (1961). Susceptibility of varieties of chrysanthemum to infestation by *Aphelenchoides ritzemabosi* (Schwartz), *Nematologica*, **5**, 297–302.

Cuttings from 13 chrysanthemum varieties were artificially infested with 110 *Aphelenchoides ritzemabosi*. Most of the cuttings in all varieties eventually showed leaf browning or distortion or blindness. Some varieties had distinctive syndromes of infestation, but there was no difference in susceptibility. Mature plants of different varieties, however, differed greatly in susceptibility. Susceptibility was not determined by stomatal size or frequency, density of epidermal hairs on leaves or stems, size of mesophyll air spaces or thickness of leaf-cell walls.

8.33. Hesling, J. J. & Wallace, H. R. (1961). Observations on the susceptibility of chrysanthemum varieties infested at two different times with chrysanthemum eelworm, *Aphelenchoides ritzemabosi*. *Nematologica*, **6**, 64–68.

The susceptibilities of different varieties of chrysanthemum to *Aphelenchoides ritzemabosi* assessed from a field experiment in 1959 were confirmed by repetition of the experiments at two different sites in 1960 when there was more rain. Many plants infested in March were later destroyed by eelworm, whereas infestations in August had no effect on the crop of blooms, although eelworm symptoms were present. When resistant varieties were infested in August symptoms did not spread because the infested leaves were killed before the eelworms could multiply and move. Many cuttings of resistant varieties, which are hypersensitive to eelworm attack, were killed.

8.34. Shepherd, A. M. (1960). A study of the apparent decay of eggs within cysts of *Heterodera schachtii* Schmidt and *H. göttingiana* Liebscher, and of free larvae in soil. *Nematologica*, **5**, 103–110.

In batches of randomly selected cysts estimates of total cyst contents based on the sum of larval emergence and residual egg count sometimes show large differences. These differences are greatest where the rates of emergence

differ most, suggesting that eggs may decay within cysts when larvae do not emerge early in the experiment. However, experiments with cysts of *Heterodera schachtii* kept in water for 2 months, and with cysts of *H. göttingiana* and *H. schachtii* kept in soil at different moisture contents, gave no evidence that many eggs are lost from cysts in this way. Usually most of the loss of cyst contents in soil can be attributed to larval emergence. The microflora present may cause occasional epidemics, especially under the conditions of hatching tests.

By contrast, larvae of *H. schachtii* rapidly decline in number in soil with a moisture content corresponding to field capacity, in the absence of a host plant. The larvae are very sensitive to soil conditions, which largely determine the rate at which they succumb.

8.35. WALLACE, H. R. (1961). The nature of resistance in chrysanthemum varieties to *Aphelenchoides ritzemabosi*. *Nematologica*, **6**, 49–58.

Leaves of resistant varieties of chrysanthemums brown quickly when infested with *A. ritzemabosi*. In such leaves eelworms do not multiply, so the infestation is isolated and does not spread. Observations on artificially infested plants in the field support this hypothesis of a hypersensitivity type of resistance. Aerated extracts of leaves of resistant and susceptible varieties brown at the same rate and have similar contents of polyphenols and phenol oxidase. Infested leaves of resistant and susceptible varieties brown at different rates because the gravid females move about freely in leaves of resistant varieties, piercing hundreds of cells which subsequently turn brown. In susceptible varieties the females do not move, pierce few cells and lay many eggs. Although 0·01*M* solutions of chlorogenic acid and quinic acid and a saturated solution of caffeic acid inhibit movement and invasion, no such effects were observed in the infested leaf, and egg laying was not affected.

8.36. WALLACE, H. R. (1961). Observations on the behaviour of *Aphelenchoides ritzemabosi* in chrysanthemum leaves. *Nematologica*, **5**, 315–321.

The length of life-cycle of *Aphelenchoides ritzemabosi* is about 10–13 days. Each female lays about 25–35 eggs in compact groups. The eggs take 3–4 days to hatch and the larvae 9–10 days to reach maturity. Fertilisation and egg laying occur chiefly at the boundary between the discoloured and green portions of the leaf. The amount of free water inside the infested leaf is determined by weather; eelworm activity in the leaf is, consequently, mainly confined to periods when there is rain or heavy mists. Early stages of chrysanthemum eelworm are more susceptible to desiccation than late stages. 95% of late stage larvae and adults emerge from leaves immersed in water for 2 days, compared with 12% of early stage larvae. Few small larvae invade leaves or migrate up the plant. Adults, unlike larvae, can swim because they generate greater propulsive forces. Adults and possibly fourth-stage larvae spread infestations.

8.37. WALLACE, H. R. (1961). Browning of chrysanthemum leaves infested with *Aphelenchoides ritzemabosi*. *Nematologica*, **6**. (In the press.)

The rate of browning of infested chrysanthemum leaves increased with relative humidity and the number of eelworms. Browning is not a continuous process because the lateral veins act as a barrier to eelworm migration within the leaf. Freeing the leaf surface and eelworms from micro-organisms did not decrease the rate of browning of chrysanthemum leaves, and the eelworm is thought to be the primary cause of leaf discoloration. The saprophytic fungus *Sporobolomyces roseus* is closely associated with browned parts of the leaf, but does not contribute to the discoloration. Chlorogenic acid, isochlorogenic acid and a glycoside of luteolin are the major polyphenolic constituents of chrysanthemum leaves. Chlorogenic acid and isochlorogenic acid are the main substrates for leaf browning, and it is suggested that, when cells are pierced by the eelworm mouth spear during feeding, the polyphenols meet the enzyme polyphenol oxidase and are oxidised and polymerised to form the brown pigments.

Insecticides and Fungicides Department

General Papers

9.1. Needham, P. H. (1960). Investigation into the use of bio-assay for pesticide residues in foodstuffs: Report by P. H. Needham. *Analyst,* Nov. 1960.

9.2. Way, M. J. (1960). Development of insect resistance to insecticides. *N.A.A.S. quart. rev.*

Research Papers

9.3. Bardner, R. (1960). Effect of formulation on toxicity to plants and insects of some systemic insecticidal seed dressings. *J. Sci. Fd Agric.* **11**, 1398–1407.

Wheat, mustard and sugar-beet seeds were treated with dressings containing certain systemic insecticides and various stickers and fillers. Activated carbon, polyvinyl acetate emulsion and a chlorinated diphenyl resin lessened the toxicity of the insecticides to seedlings grown in sand. Polyethylene glycol ethers and polyvinyl alcohol solution also had some effect. Carbon and polyvinyl acetate prolonged the period of systemic action of " Thimet " against the mustard beetle *Phaedon cochleariae* F. and the bird-cherry aphid *Rhopalosiphum padi* L. Mustard plants grown from seed treated with γ-BHC formulated with these materials were slow to attain their maximum insecticidal activity. These effects are attributed to the initial absorption of insecticide by the sticker or filler and its subsequent slow release. Formulations permitting the slow release of insecticides have a practical use because they can combine low phytotoxicity with a long persistence of systemic insecticidal activity.

9.4. Broadbent, L., Heathcote, G. D. & Burt, P. E. (1960). Field trials on the retention of potato stocks in England. *Eur. Potato J.* **3**, 251–262.

(For summary see no. 7.16 on p. 285.)

9.5. Burt, P. E., Broadbent, L. & Heathcote, G. D. (1960). The use of soil insecticides to control potato aphids and virus diseases. *Ann. appl. Biol.* **48**, 580–590.

A replicated trial was done to find whether the insecticides " Thimet " and " Rogor " applied in the soil affected the spread of aphid-transmitted viruses from infected to healthy plants within potato crops. The insecticides were applied at planting as activated carbon formulations at rates equal in cost to three sprays with DDT emulsion at 2 lb. DDT/acre. The infected plants were removed (rogued) in late June.

" Thimet " applied along the furrows with the fertiliser, and " Rogor " applied in individual doses beneath each tuber, kept the plants free from aphids from a week after the plants emerged until early August. " Thimet " in individual doses was less effective, but greatly decreased the aphid infestation. All treatments prevented or greatly decreased the spread of leaf-roll virus, but they only slightly decreased the spread of virus Y. No treatment damaged the plants or depressed yields significantly.

Tubers harvested from the plots treated with insecticides contained only very small quantities of the insecticides, but shoots from them, when infested with adult *Myzus persicae* (Sulz.), carried fewer aphids a week after infestation than did shoots from control tubers. Shoots of tubers from treated plots also grew more slowly than those from the controls.

The aphicidal efficiency of " Thimet " applied as individual doses separated from the tubers by distances of up to 6 inches, decreased as the distance increased, but the effect of distance became less as time passed.

Reasons for the differences in the behaviour of the insecticides are discussed, and the possibilities that the method offers to control virus diseases. The application of insecticides to soil promises to be a useful way of controlling the spread of viruses, provided the harvested crop is free from toxic residues.

9.6. Das, M. (1961). Effect of time and temperature on toxicity of insecticides to insects. II. Tests of DDT on adult *Tenebrio molitor* L. below 10° C. *Ann. appl. Biol.* **49**, 39.

The toxicity of DDT to insects usually increases as the post-treatment temperature is decreased in the commonly used temperature range (30–10°). The toxicity increased further when the post-treatment temperature of adult *Tenebrio molitor* L., dosed by topical application, was decreased from 10° to 6°. Howevef, when the post-treatment temperature was decreased still more (down to −1°), the toxicity by topical application or by injection apparently decreased again. The size of this " positive temperature coefficient " below 6° decreased as time passed after treatment. Differences in toxicity below 6° were more apparent than real, and were the result of differences in the speeds at which symptoms appeared.

The slight toxic action at very low temperatures was evidently not caused by failure of DDT to penetrate the cuticle, or to reach its site of action. More probably, the speed of the chemical or physical process which actually caused paralysis was extremely low at the very low temperatures.

9.7. Das, M. & McIntosh, A. H. (1961). Effect of time and temperature on toxicity of insecticides to insects. III. Tests of seven poisons in the range 10–28° C. *Ann. appl. Biol.* (**49**, 267–289.)

The contact poisons rotenone, 5:5-dimethyldihydroresorcinol dimethylcarbamate (" Dimetan "), 2-bromomercurithiophen, 2-*iso*valeryl-1:3-indandione (" Valone "), α-chlordane, toxaphene and DDT were tested, in probit assays, on as many as possible of four insect species (*Oryzaephilus surinamensis* L., *Tribolium castaneum* Herbst, *Tenebrio molitor* L. and *Musca domestica* L.) by applying the poison so that there was no " pick-up " effect, and then keeping the insects at each of two post-treatment temperatures (usually 10 and 28°) for as long as possible.

The same insects were counted repeatedly throughout each test. At each counting, the two ED50's were found, and from these the temperature coefficient of toxic action (ratio of ED50's) was calculated; temperature coefficients were " positive " or " negative ", according to whether the toxic action was greater or less at the higher temperature. The time for each ED50 to decrease to a steady value (the end-point) was also found; the inverse of this time was the " speed of action " of the poison. In some tests the end-points were not reached, even though the insects were kept until the proportion dead in the control batches reached about 40%. Temperature coefficients, measured soon after treatment, were most probably temperature coefficients of paralysis only; and those at the end of the test, coefficients of kill, with continuous gradation between.

The results were characteristic of the poison used, and not of the test species.

Rotenone and " Dimetan " each caused an initial paralysis, from which the insects temporarily recovered before dying. In the tests with rotenone, increase in post-treatment temperature increased the speed of the sequence knockdown–recovery–death, and probably the speed of action; the initial temperature coefficient (of paralysis) was negative, but it changed to a positive coefficient as time passed; end-points were not reached. Results with " Dimetan " were somewhat similar, but the coefficients were very small and variable in sign.

In the tests with 2-bromomercurithiophen, " Valone ", α-chlordane and toxaphene, the transition from the initial paralysis to death was not interrupted by a period of recovery; all the ED50's decreased steadily in size as time passed, and the observed decrease was greater at the lower temperature. Increase in post-treatment temperature nearly always increased the speed of action, which was greater with " Valone " than with any of the other poisons. The temperature coefficients were initially positive, but became smaller or sometimes negative as time passed, so that an increase in post-treatment

temperature either did not affect the ultimate toxicity (2-bromomercurithiophen and some tests with " Valone ") or decreased it (α-chlordane, toxaphene and the other tests with " Valone "); increase in post-treatment temperature also increased the curvature of the line relating ED50 to time after treatment.

In the tests with DDT, which include one series by injection, the ED50's also decreased steadily as time passed, but the temperature coefficients were consistently negative. Increase in post-treatment temperature did not affect the shape of the ED50–time curve; no general statement can be made about the effect of temperature on speed of action.

Thus, a change in post-treatment temperature can affect the course of poisoning of contact insecticides by affecting their speed of action (which usually increased with post-treatment temperature), or the ultimate toxicity, or the shape of the ED50–time curve, or in some combination of these ways.

Some of the theories about the causes of the negative post-treatment temperature coefficient of DDT are discussed.

9.8. Das, M. & Needham, P. H. (1961). Effect of time and temperature on toxicity of insecticides to insects. I. Tests of DDT on larvae of *Aëdes aegypti* L. *Ann. appl. Biol.* **49**, 32.

The effects of a change in temperature (15–28°) on the toxicity of dilute suspensions of DDT to larvae of *Aëdes aegypti* L., as assessed by a photomigration method, depended on the stage of the test during which the temperature was changed. Increase in temperature during exposure to DDT (0·02 p.p.m. for about 1 hour) increased the toxic action. When larvae were left in the suspensions for the duration of the test (3 hours–4 days), increase in temperature throughout the test decreased the toxic action of a very low concentration of DDT (0·002 p.p.m.), but had no effect with higher concentrations (0·1–0·2 p.p.m.). Toxic action was greater in larvae held at a low temperature than in larvae held at a high temperature after treatment (0·025 p.p.m. for 3 hours). Such toxic action was reversible: a change from high to low temperature increased paralysis, and larvae, paralysed at a low temperature, recovered when the temperature was raised.

9.9. Elliott, M. (1960). Pyrethrolone and related compounds. *Chem. & Ind.* 1142.

The isolation of pyrethrolone and cinerolone from pyrethrum extract is described; these alcohols with chrysanthemic and pyrethric acids gave pyrethrins I and II and cinerins I and II. The optical rotations of the four esters, earlier in dispute, are discussed. Whereas cinerolone and its derivatives (including cinerins I and II) are stable to heat, pyrethrolone and its derivatives (including pyrethrins I and II) undergo thermal isomerisation, and the side chain double bonds migrate into conjugation with the cyclopentenone ring. These isomerisations increase the negative rotations of the compounds, which probably explains the conflicting optical rotations reported for the pyrethrins. The fifth and sixth pyrethrolone semicarbazones, obtained by earlier workers, are considered to be formed by thermal isomerisation during the isolation procedure, which involved rigorous fractional distillation.

9.10. Elliott, M. (1960). The structures of the enols of pyrethrolone. *Proc. chem. Soc.* 406.

Hot methanolic sodium ethoxide converts pyrethrolone into cyclopentanedione (high-boiling enol) and into a cyclopentenedione which has only one side chain double bond (low-boiling enol). The structures of these products were earlier in doubt.

9.11. Elliott, M. (1961). Pyrethrins and related compounds II. Infra-red spectra of the pyrethrins and of other constituents of pyrethrum extract. *J. appl. Chem.* **11**, 19.

Infra-red spectra have been widely used in investigations on the pyrethrins and related compounds since 1950, and two analytical methods using infra-red have been described. Crombie stressed the importance of infra-red spectra as criteria of purity and for the elucidation of the structure of compounds in this series, which are often viscous liquids of high boiling point that do not

give derivatives readily. Yet the spectra of the four insecticidal esters themselves (pyrethrins I and II, and cinerins I and II, Fig. 1) have not been published. The spectra of these four compounds are here compared and contrasted with each other and with those of the alcohols, [(+)-pyrethrolone and (+)-cinerolone] and acids [(+)-*trans*-chrysanthemic acid and (+)-*trans*-pyrethric acid] from which the esters are constituted. Further, to help identify the compounds present in flower extracts or other pyrethrum preparations, the spectra of pyrethrosin, of pyrethrol and of the hydrocarbons in the waxes are recorded.

9.12. Last, F. T. (1960). Longevity of conidia of *Botrytis fabae* Sardiña. *Trans. Brit. mycol. Soc.* **43**, 673–680.

The numbers of conidia produced by *Botrytis fabae* on agar media increased up to the 10th day after inoculation, when the average age of conidia was 3 days. Germination in water of conidia from cultures differing in age between 10 and 40 days was equally high, but those from cultures 25 and 35 days old were only $\frac{1}{10}$ and $\frac{1}{100}$ as infective as conidia from 10-day-old cultures.

Suspending conidia from cultures up to 40 days old in a solution (0·2% or higher concentration) of either yeast extract or orange juice partially restored infectivity, as did solutions of sucrose, glucose, mannose and maltose, but fructose and galactose were less effective. Arabinose, xylose, casein hydrolysate, peptone and nucleic acid did not increase infectivity.

Abrading leaves with " Celite " before inoculation increased the numbers of infections produced by spores suspended in water; the increase, as with adding sugars, was greater with old than with young conidia.

9.13. Last, F. T. (1960). Effect of cultural treatments on the incidence of *Striga hermonthica* (Del.) Benth. and yields of sorghum in the Sudan: Field experiments 1957/8. *Ann. appl. Biol.* **48**, 207–229.

Trap-cropping, nitrogenous fertilisers, selective weed-killer sprays (2:4-D) and sorghum varieties affected the incidence of *Striga hermonthica*.

S. hermonthica developed more on the variety Debekri than Feterita. Usually, applying increasing amounts of nitrogen (sulphate of ammonia or urea) progressively decreased the incidence of *S. hermonthica* on Feterita, Dwarf White Milo and Wad Fahl. Early applications were more effective than late applications. Nitrogen given to Debekri never significantly decreased the amount of *S. hermonthica*, and often increased it.

In an experiment on very infertile and heavily infested soil, nitrogen increased the amounts of *S. hermonthica* on all varieties, but less on Feterita than Debekri. The weights of *S. hermonthica* on Feterita reached a maximum with 40 lb. N/acre, but were still increasing after adding 80 lb. N to Debekri.

Weed-killer sprays affected *S. hermonthica* on Feterita and Debekri equally. They delayed the appearance of its aerial stems and usually decreased their subsequent growth. Spraying with 1·6 lb. 2:4-D/acre was usually more effective than with 0·8 lb., and sometimes spraying 3 weeks after sowing was better than after 2 weeks.

Trap cropping with Sudan grass (*Sorghum sudanense*) for 5 weeks, but not for 3, significantly decreased the incidence of *S. hermonthica* in succeeding sorghum crops, and sometimes increased grain yields.

Phosphorus and potassium affected neither the incidence of *S. hermonthica* nor sorghum yields. On lightly infested soil where *S. hermonthica* was not damaging, 80 lb. N/acre trebled grain yields (from 1,140 to 3,530 lb./acre). As infestations increased in severity, the absolute gains decreased, but the relative effects were greater. On crops infected early and severely, yields increased by 820% from 180 to 1,505 lb./acre. Nitrogen applied at sowing and after 3 weeks gave larger increases than later applications.

Yield increases caused by 2 : 4-D sprays are associated with the delayed emergence of aerial stems of *S. hermonthica*. Where infection developed rapidly and the mean levels of infection were at least 20% within 50 days of sowing, sprays increased both grain and straw yields; where infection developed slowly, only grain yields were increased. Although 1·6 lb. of 2 : 4-D/acre decreased *S. hermonthica* more than 0·8 lb., they affected yields equally, as did spraying 2 or 3 weeks after sowing.

0·8 lb. of 2 : 4-D/acre and 80 lb. N/acre when applied separately to severely infected crops increased grain yields from 38 lb. in the untreated plots to only 163 and 588 lb./acre respectively, whereas applied together they gave 2,170 lb./acre. In the same experiment nitrogen increased the yields of the less heavily infected Feterita more than those of Debekri. 2 : 4-D affected both varieties similarly.

9.14. Last, F. T. (1960). Incidence of *Striga hermonthica* (Del.) Benth. on two varieties of irrigated sorghum differently manured, spaced and thinned. *Trop. Agric. Trin.* **37**, 309–319.

Foliage of the semi-parasitic *Striga hermonthica* growing on two sorghum varieties, Dwarf Hegari and Feterita 1931, was collected, air dried and weighed on four occasions. It grew at different rates at different stages of sorghum development and reached a peak *ca.* 5·4 lb./acre/day from 65 to 80 days after planting. Less developed on Dwarf Hegari than on Feterita.

Adding 80 lb. N/acre, as sulphate of ammonia, increased grain and straw yields, but decreased the total aerial growth of *S. hermonthica* from a mean (for the two varieties) of 245 lb. in unmanured crops to 98 lb./acre. The decreases were relatively smaller from 51 to 80 days after planting sorghum, when *S. hermonthica* was developing rapidly, than in earlier and later stages of the host's growth.

Straw yields of unmanured crops of both varieties were similar, *ca.* 3,350 lb./acre, but Dwarf Hegari yielded more grain. Adding 80 lb. N/acre increased straw yields of the long-strawed Feterita to 9,000 lb. and of the short-strawed Dwarf Hegari to 7,350 lb./acre: it increased mean grain yields of both varieties similarly, from 760 to 3,540 lb./acre.

Widening the spaces between planting holes from 25 to 100 cm. and thinning the number of plants per hole from eight to two did not affect the yields of grain per acre, but quadrupled the yields per plant of both varieties; the straw yields per plant increased by a factor of about $\times 3{\cdot}2$, instead of $\times 4{\cdot}0$, with consequent significant decreases per acre. Yields of grain per acre were the same over the whole range of plant populations given by combinations of the various spacing and thinning treatments, viz., 10,000–160,000 plants/acre, but straw yields increased progressively with increasing plant number.

In the first 7 weeks after planting spacing affected weights of *S. hermonthica* per acre but not weights per host—less *S. hermonthica* grew per acre on widely than on closely spaced crops of both varieties. Later, more *S. hermonthica* developed per host spaced at 50 and 100 than at 25 cm., so masking the earlier effects per acre; the increases on Dwarf Hegari were less than on Feterita.

From the start, four times as much *S. hermonthica* grew per host where there were two instead of eight plants/hole, and as a result the weights per acre were unaffected.

9.15. McIntosh, A. H. (1961). Graphical and other short statistical methods for all-or-none bioassay tests. *J. Sci. Fd Agric.* **12** (4).

The full probit method, although time-consuming, is often used to make a statistical analysis of the figures obtained in all-or-none bioassay tests of insecticides or fungicides.

Many rapid approximate methods have been devised as substitutes. One of these is based on ranking; others are arithmetic; and others, based on the use of probits, are graphical.

Logits or angles can be used instead of probits, and often give almost identical results. Each can be calculated on a slide-rule; most of the rapid graphical methods can be applied when they are used; and the method for doing a full analysis is simplest when angles are used.

9.16. McIntosh, A. H. (1961). Some variants and possible errors in the test tube dilution and slide-germination methods for laboratory testing of fungicides. *Ann. appl. Biol.* **49** (3).

A method is given for moulding uniform perspex cavity slides, which are quickly made, almost unbreakable and without joints; they can withstand

strong alkalis, but not strong acids or solvents, and are useful for spore-germination tests of water-soluble fungicides. When the drops of spore suspension–poison mixture in the cavities of these slides or of Böttcher's glass cavity slides are enclosed by cover slips, there is no meniscus effect, and in tests of long duration the same spores can be counted repeatedly.

In such tests errors may arise from sorption of poison on the surfaces of pipettes and tubes (dilution stage) and on slides and cover slips (incubation stage); and from changes in the volume of the drops (incubation stage).

Ions of many metals may be lost by sorption, and the losses are often greater on soft than pyrex glass. Hg was lost rapidly. In a three-stage serial dilution of $HgCl_2$ solution in soft glassware from 60 to 1·0 p.p.m. of Hg, the loss in strength was 27%. More Hg was lost from $HgCl_2$ than from phenyl mercuric acetate solutions. The losses on glass or perspex slides with cover slips from solutions containing 1·0 p.p.m. of Hg (but no spores in suspension) were 30–35% in 15 minutes and 61–74% in 24 hours with $HgCl_2$, but only 5–10% on glass and 35–37% on perspex slides in 24 hours with phenyl mercuric acetate. Increase in temperature (10–25°) slightly increased the loss from $HgCl_2$ but not from phenyl mercuric acetate solutions. Perspex slides, which were used repeatedly for tests of water-soluble mercury compounds and washed in distilled water after each test, eventually became toxic to conidia of *Botrytis fabae* Sardiña.

When the slides, with drops, are placed in moist chambers for incubation, some evaporation is unavoidable because the air close to them is not initially saturated with water vapour. When the chambers were pre-cooled or pre-warmed, so that the temperature of the air in them was uniform, the loss from 0·30-ml. drops in cavity slides was not serious (about 8%, with or without cover slips, in 48 hours at 10° or 25°). But when the temperature was not uniform, the possibilities of change in drop volume were much greater: in 48 hours, the volume of open drops could decrease by evaporation (44% loss at 10°) or even increase slightly by condensation (3% gain at 25°). When spores have to be counted on several occasions, the evaporation losses may be more serious.

9.17. Potter, C., Lord, K. A. & Solly, R. (1960). The mode of action of organophosphorus compounds on insect eggs with special reference to their anti-esterase activity. *Proc. 4th int. Congr. Crep. Prot.* 1957, **2**, 1169–1172.

The hydrolysis of acetyl choline, triacetin and phenyl acetate by homogenates of eggs of *Pieris brassicae* and *Gryllus domesticus* was examined. Enzyme kinetic and inhibition and activation studies indicated that the same enzymes were not present throughout the development of the eggs and that complexes of enzymes were responsible for the hydrolysis of triacetin and phenyl acetate.

The amounts of organophosphorus insecticides to prevent the hatch of *Pieris brassicae* eggs vary with the age of the eggs when the poisons are applied. With increasing age the eggs become more susceptible to TEPP, less susceptible to " Para-oxon " but show little change in resistance to " Dipterex ". No relationship between the occurrence of esterases and susceptibility to insecticides was deduced.

9.18. Sawicki, R. M. (1961). A technique for the topical application of poisons to non-anaesthetised house flies for knockdown assessments. *Bull. ent. Res.* **51**, 715.

When a spraying technique is used to assess " knockdown ", the amount of insecticide picked up by the flying insects varies and is very difficult to determine. For this reason, topical application, whereby each insect is treated with a given dose of poison, would be preferable, but till now was unsuitable for measuring knockdown, because there was no efficient method to immobilise the insects during dosing. Anaesthetics or cooling affect the response of the insects to the insecticides, using suction to immobilise the insects during dosing means that the insects have to be handled individually, which is laborious and time-consuming.

The method described is rapid; the treatment time of a batch of 10 insects

seldom exceeds 10 seconds, and the total handling time is about 3 minutes. The difference between the dosing time of the first and last insects of a batch is negligible, and the knockdown can be assessed within 15 minutes of dosing.

9.19. Sawicki, R. M. & Thain, E. M. (1961). The chemical and biological examination of commercial pyrethrum extracts for insecticidal constituents. *J. Sci. Fd Agric.* **12**, 137.

Samples of three commercial pyrethrum extracts were examined chemically and biologically to determine the number of insecticidal constituents they contain. These constituents, which were completely removed from commercial pyrethrum by exhaustive extraction with nitromethane, were separated by displacement chromatography. The insecticidal activity of the eluate was restricted to fractions identified chemically as cinerin I, pyrethrin I, cinerin II and pyrethrin II. Solutions containing the four pure active constituents in the same ratios as in the three commercial extracts had the same activity as the corresponding extracts. If any other insecticidal constituent occurs in commercial pyrethrum extract, its contribution to the total activity is negligible.

9.20. Way, M. J. (1960). Bean aphid control on field beans in relation to the flowering period and to possible honey bee poisoning. *Plant Path.* **10**, 14.

One correctly timed spraying with a suitable systemic insecticide will effectively control *A. fabae* on field bean crops sown before about the beginning of April. The sowing date determines whether the beans are in flower when the insecticide is applied. February-sown crops are likely to be in full bloom when they need spraying, and therefore may be especially dangerous to bees. Autumn-sown crops and crops sown after mid-March will have flowered or not yet flowered, though some bees may be visiting their extra-floral nectaries.

The main recurring danger to bees visiting field beans seems to be from the unnecessarily late spraying with non-selective insecticides of crops sown in March or April.

Entomology Department

Doctoral Theses

10.1. Gerard, B. M. (1960). The biology of certain British earthworms in relation to environmental conditions. Ph.D. Thesis, University of London.

General Papers

10.2. Edwards, C. A. & (Gunn, E.) (1960). Autumn tests show better ways to control millipedes. *Comm. Grower*, 591.

10.3. Mellanby, K. (1960). Publication of the results of biological research. *J. Inst. Biol.* **7**, 83–85.

Research Papers

10.4. Barnes, H. F. (1960). The resistance of some American wheats to hessian fly of mixed foreign parentage. *J. Kansas ent. Soc.* **33**, 37–44.

Eight American varieties of wheat, resistant to American hessian fly, also had comparable resistance to hessian fly of mixed foreign parentage.

10.5. Barnes, H. F. & Arnold, M. K. (1960). The susceptibility of some American wheats to the wheat blossom midges. *J. Kansas ent. Soc.* **33**, 165–174.

Seven American varieties of wheat resistant to hessian fly and one susceptible to it are susceptible to *Contarinia tritici* (Kirby), which is not yet known to occur in North America. All these are also susceptible to the other wheat blossom midge, *Sitodiplosis mosellana* (Gehin), which does occur in North America. Marquillo-Oro × Triunfo (12858) seems to be less susceptible. The information gained about three other varieties, Marquardts, Durum and Peko, must be discounted, because their ear-burst did not coincide with the midges' flight period.

10.6. Barnes, H. F. & Arnold, M. K. (1960). Delayed emergence of the pea midge. *Plant Path.* **9**, 52–54.

More *C. pisi* that had completed their larval feeding in the field during 1957 emerged in the Rothamsted Lodge insectary in 1959 than in 1958. A sudden increase in number of emergences occurred in a thundery period in 1959. There are indications that unisexual families occur in the pea midge. The emergence of *S. mosellana*, one of the wheat blossom midges, after spending 18 years as a fully fed larva is noted.

10.7. Bett, J. (1960). The breeding seasons of slugs in gardens. *Proc. zool. Soc. Lond.* **135**, 559–568.

Generalised life cycles of five slug species were ascertained from new data, and Barnes & Weil's unpublished data, on weights of individual slugs together with information on the seasonal state of their genital organs.

Arion hortensis hatches mainly in January and February, grows through the summer months to become mature in September and October. These adults live through the winter, laying eggs and gradually losing weight, and die before July of the following year.

The eggs of *Arion subfuscus* are mainly laid in the autumn (late August and September) and hatch sporadically through the winter. The young slugs grow through the spring to become mature in July, and the adults die soon after egg-laying.

Agriolimax reticulatus breeds throughout the year, but the rate depends on the weather and each year there is a period of intense egg-laying associated with the new spring vegetation, giving a summer abundance of individuals.

Milax budapestensis hatches during the autumn and winter, grows through the summer to become mature in late October and November when they mate and eggs are laid in the autumn and throughout the winter. The adults die before July of the following year.

Milax sowerbii probably hatches in early spring, grows throughout the summer, becomes mature, mates and starts to lay eggs in September, October and November. The adults die soon after egg-laying.

10.8. Cockbain, A. J. (1961). Fuel utilization and duration of tethered flight in *Aphis fabae* Scop. *J. exp. Biol.* **38** (in the press).

Glycogen is used during early flight, but fat is the principal fuel after the first hour and provides about 90% of the energy for a flight of 6 hours. Most of the fat and glycogen reserves are in the fat-body cells of the thorax and abdomen. Calculated metabolic rates during tethered flight ranged from 52–66 cal./g. live wt./hour and 400–500 cal./g. flight muscle/hour. Flight capacity at 25° was directly related to initial fat content and varied between 3 and 8 hours in laboratory-reared aphids and 7 and 12 hours in aphids from a natural infestation.

10.9. Cockbain, A. J. (1961). Water relationships of *Aphis fabae* Scop. during tethered flight. *J. exp. Biol.* **38** (in the press).

Water loss from tethered aphids during flight was by evaporation and excretion; at least 66% of the loss was by evaporation. The relative amounts

of water loss during prolonged flight were inversely related to relative humidity. The proportion of water in the body and the hydration of lean dry matter remained almost constant during flights of 6 hours. Water loss is not a limiting factor to flight in saturation deficits less than *c.* 23 mm. Hg.

10.10. Cockbain, A. J. (1961). Viability and fecundity of alate alienicolae of *Aphis fabae* Scop. after flights to exhaustion. *J. exp. Biol.* **38** (in the press).

Longevity, reproductive rate and capacity, and nymph viability of aphids flown to apparent exhaustion (for 3–9 hours), and subsequently allowed to feed on host plants, were similar to those of aphids flown for only $\frac{1}{4}$ hour. Unlike fresh aphids, exhausted ones were unable, or reluctant, to fly on the following day, possibly because of the early onset of flight muscle autolysis. Results indicate that long migratory flights are unlikely in themselves to affect the reproductive potential of aphids, and that alienicolae of *A. fabae*, having settled on a suitable host after exhaustion, are unlikely to fly again.

10.11. Dobson, R. M. & Morris, M. G. (1961). Observations on emergence and life-span of wheat bulb fly (*Leptohylemyia coarctata* (Fall.)) under field-cage conditions. *Bull. ent. Res.* **51**, 803–821.

Emergence and life-span of wheat bulb fly (*Leptohylemyia coarctata* (Fall.)) were studied by the use of the " Field-Cage-Marking " technique. Emergence was investigated by observing the numers of flies emerging daily from an area of infested wheat enclosed by a cage of fine mosquito netting, and life-span by making a daily census of marked and individually recognisable flies which had been liberated in the cage. Flies were handled only when being marked, and in the latter part of the work all observations were made without touching either them or the wheat.

Flies were chilled to render them comatose for marking and under certain circumstances this and the marking was harmful. Attempts were made to decrease these harmful effects.

Emergence dates varied from year to year, depending on the temperatures of spring and early summer, and there were also considerable differences between the emergence dates of populations of adjacent fields in the same year. Consistently, males appeared before females.

The ratio of flies seen to the number known to be alive on each day varied according to weather, and flies were more difficult to find on windy days than on calm ones and on bright days than on dull ones.

The observed life-spans of both sexes varied greatly—up to a maximum of 75 days for females and 55 days for males. An exact statement of mean life-span was, however, valueless because there was a tendency for flies emerging later in the season to be less long-lived than those emerging earlier. Most flies of both sexes lived for over 30 days. The observed life-spans fall short of the true life-spans by amounts which depend on the proportions of living flies seen each day. Two methods are shown by which the mean unrecorded life-span can be calculated.

10.12. Edwards, C. A. (1960). The ecology of Symphyla. Part II. Seasonal soil migrations. *Ent. exp. & appl.* **2**, 257–267.

Seasonal changes in the vertical distribution of *Scutigerella immaculata* Newport and *Symphylella vulgaris* Hansen in cultivated soils were studied. In bare soil outdoors there were high surface numbers in spring, low in summer with a second increase in autumn. The distribution pattern was similar in bare greenhouse soil, except that spring migrations to the surface soil occurred earlier, the summer exodus from the surface was more marked and the autumn increase much reduced. Growing plants attracted *Scutigerella immaculata* to the surface even under adverse soil conditions, but had little influence on *Symphylella vulgaris*. The results are discussed in relation to other work.

10.13. Edwards, C. A. & (Dennis, E. B.) (1960). Observations on the biology and control of the Garden Swift Moth. *Plant Path.* **9**, 95–99.

The Garden Swift moth, *Hepialus lupulinus* L., is a common soil pest of horticultural crops. The host range of this pest is reviewed and added to. Winter attacks of lettuce and anemones by the larvae were studied and replicated trials made to test the efficiency of DDT, BHC, dieldrin and aldrin soil drenches. Of the materials tested a solution of DDT emulsion containing 0·05 a.i. was both the most effective, cheapest and most persistent. Evidence was accumulated that the moth completes its life cycle in one year.

10.14. Edwards, C. A. & (Dennis, E. B.) (1960). Some effects of aldrin and DDT on the soil fauna of arable land. *Nature, Lond.* **188**, 767.

The effects of rates of insecticides commonly used on the soil fauna of fallow arable land were studied in a replicated trial. Sixteen 2-inch diameter soil cores were taken from each treatment at 2–3 monthly intervals and the fauna extracted by a modified Salt and Hollick technique. Aldrin decreased and DDT increased the Collembola population. Both insecticides very significantly decreased the populations of mites, dipterous and coleopterous larvae, thrips, pauropods and symphylids. Numbers of root aphids were greatly decreased by aldrin, but not by DDT; neither insecticide affected the populations of earthworms and enchytraeid worms significantly.

10.15. French, R. A. & (White, J. H.) (1960). The Diamond-back Moth outbreak of 1958. *Plant Path.* **9**, 77–84.

At the end of June and the beginning of July 1958 a large immigration of the Diamond-back Moth (*Plutella maculipennis* (Curt.)) occurred on the east coasts of England and Scotland. The entomological information indicated that these insects had come from an easterly direction, possibly from North-West Russia. Trajectories of the winds blowing at this time lead back to a similar region and, by their use, an attempt is made to delineate approximately the area of origin.

10.16. Heath, G. W. (1960). Ley deterioration and soil insects. *J. Brit. Grassl. Soc.* **15**, 209–211.

Two insecticides were applied to a 5-year-old ley and their effects on yield and soil fauna were studied a year later. Aldrin (2 lb. actual toxicant/acre) or dieldrin (1 lb. actual toxicant/acre) was incorporated in a standard dressing of compound fertiliser.

One year after treatment the yield of dry matter was significantly higher on dieldrin plots than on plots receiving fertiliser alone. The soil fauna was examined in dieldrin and control plots. The wireworm (*Agriotes* spp.) populations were 80,000 and 400,000 per acre respectively. The increase in herbage yield was ascribed to the decrease in number of wireworms. Mite and Collembola populations were very significantly decreased by dieldrin: the effect of this on the breakdown of soil organic matter is discussed. Predaceous insects were effected by insecticides, but their resurgence rate can be expected to keep pace with that of wireworms.

10.17. Johnson, C. G. (1960). A basis for a general system of insect migration and dispersal by flight. *Nature, Lond.* **186**, 348–350.

Whenever the beginning of a mass migration has been recorded it has shown that the migrants are relatively newly emerged insects on a very early, often the first, flight. The consequences of this to the general approach to migration and dispersal studies is discussed.

10.18. Johnson, C. G. (1960). The relation of weight of food ingested to increase in body-weight during growth in the bed-bug, *Cimex lectularius* L. (Hemiptera). *Ent. exp. & appl.* **3**, 238–240.

The increase in body weight of successive instars (weighed before feeding) is of the order of 30% of the weight of the food (blood) ingested at each instar

except with the 1st-2nd instar, where it is approximately 40%. The gross efficiency with which food is used to increase body weight does not vary appreciably with temperature between 20° and 30°.

10.19. Long, D. B. (1960). Larval movement and infestation in the wheat bulb fly, *Leptohylemyia coarctata* Fall. *Bull. ent. Res.* **51**, 405–414.

The ability of newly hatched larvae of the wheat bulb fly to move through 9 inches of soil and infest wheat plants depends on the nature of the soil and its pH. In the soils tested larvae were most successful in sandy loam, 28% infesting plants, less so in clay loam, 19% and least in peaty loam, 2%. Larvae-infested plants grown in clay loam within a pH range of 4·9–7·8 with a possible optimum at pH 6·2. The relative failure to infest in peaty loam is apparently because this soil impedes larval movement rather than it interferes with the finding of host-plants.

In plot experiments no predominating direction of larval movement was observed. Newly hatched larvae can travel up to at least 21 inches before they enter a shoot and feed. Three-quarters of the larval life may be spent in this shoot, while the weight increases about 60 times. Movement is usually from this shoot to another along rows. In subsequent feeding, larval weight increases by a further factor of 15. The larvae damaged an average of two shoots each and travelled up to a maximum distance of 33 inches, measured in a straight line from point of release, throughout their entire life-span.

10.20. Mellanby, K. (1961). Slugs at low temperatures. *Nature, Lond.* **189**, 944.

Slugs can move and feed at low temperatures, so are well fitted to be agricultural pests in winter. *Agriolimax reticulatus* is active below 0·8°, *Arion hortensis* is seldom active below 5°. No acclimatisation to high or low temperatures was found in slugs, which thus differ from many insects, amphibia and fish.

10.21. Miller, B. S. & (Swain, T.) (1960). Chromatographic analyses of the free amino-acids, organic acids and sugars in wheat plant extracts. *J. Sci. Fd Agric.* **6**, 344–348.

Plants of three hard red winter wheat varieties differing in their resistance to attack by hessian fly (*Mayetiola destructor* Say) were compared at the fourth leaf stage for their content of constituents extractable by 80% ethanol. Eleven emino-acids, five organic acids and two inorganic acids were identified. Seven sugars were separated, two of which were unidentified polysaccharides. The main difference was that the susceptible variety (Tenmarq) contained allulose, or allulose in combination with some other component. The semi-resistant variety (Ponca) contained less allulose and the resistant variety (C.I. 12855) contained none. Sorbitol was found in Tenmarq, but not in the other varieties.

10.22. Milne, D. L. (1960). The gall midges (Diptera: Cecidomyidae) of clover flowerheads. *Trans. R. ent. Soc. Lond.* **112**, 73–108.

A study of the gall midge (Diptera: Cecidomyidae) fauna of clover heads has shown that there are three species, namely *Dasyneura leguminicola* Lintner, *D. gentneri* Pritchard and *Tricholaba barnesi* sp. n., whose larvae destroy clover seed in Britain. *Dasyneura gentneri* and *D. leguminicola* are separated morphologically and biologically. The morphological criteria used are demonstrated to be valid in separating other closely allied *Dasyneura* species, namely *D. mali* Kieffer from *D. pyri* Bouche and *D. affinis* Kieffer from *D. violae* Loew.

Seven other gall midge species occur on clover heads in Britain. The larvae of two of these, *Phaenobremia aphidivora* Rübsaamen and *Lestodiplosis trifolii* Barnes, are predatory on aphids and other gall midge larvae, respectively. The feeding habits of the remaining five species, namely *Clinodiplosis leguminicola* sp. n., *Giardomyia britannica* sp. n., *Isodiplosis deutera* sp. n., *Brachyneura squamigera* Winnertz and *Contarinia* sp., are not known, although

it is suggested that larvae of *Isodiplosis deutera* may feed on decomposition products or on fungus spores.

Illustrated keys are given for the identification of males, females and larvae of gall midges occurring on clover heads in Britain.

10.23. Raw, F. (1960). Observations on the effect of hexoestrol on earthworms and other soil invertebrates. *J. agric. Sci.* **55**, 189–190.

When hexoestrol or stilboestrol is used to aid meat production most of the oestrogen is excreted by the treated animals, and so reaches the soil, where it may affect the soil fauna.

Laboratory experiments showed that activity of *L. terrestris*, *A. caliginosa* and *A. chlorotica* was unaffected by 15 mg. hexoestrol in 500 g. of soil. Activity and reproduction of *A. caliginosa* was unaffected by 10 mg. hexoestrol in 500 g. soil, but 100 mg. and over affected activity and stopped reproduction. This is far in excess of amounts ever likely to be reached in land grazed by treated cattle. Egg capsules of *A. caliginosa* and *A. chlorotica* developed normally in a saturated aqueous solution of hexoestrol.

When grass plots grazed by treated and untreated bullocks were sampled no effect on the soil fauna due to grazing by implanted bullocks was observed.

10.24. Raw, F. (1960). Earthworm population studies: a comparison of sampling methods. *Nature, Lond.* **187**, 257.

The accuracy of estimates of earthworm populations got by hand sorting soil samples was tested by using a washing method to see how many more worms could be recovered from soil samples already hand sorted.

Hand sorting recovered only 52% of the number and 84% of the weight of worms from samples from wet hill grassland with a surface mat and poor soil structure; proportionately more of the large than of the small worms were recovered. Hand sorting was no quicker than washing.

With soil samples from grassland with no surface mat on a light and a heavy well-drained soil, hand sorting recovered 89% of the total number and 95% of the total weight of worms found, and was much quicker than washing, but with samples from an old arable field on heavy soil with poor structure, hand sorting recovered only 59% of the total number and 90% of the total weight of worms found, and was no quicker than washing.

The washing method checks the efficiency of hand sorting, and, for some habitats, more accurately estimates the population.

10.25. Riches, J. (1960). Damage to the oat panicle by the Frit Fly. *Ent. exp. & appl.* **3**, 173–184.

About 2,000 panicles (60,000 spikelets) of known bursting date from small plots of oats were dissected. Spraying young oat plants with DDT against first-generation attack also decreased panicle attack. The spraying causes physical differences between the sprayed and the unsprayed areas—namely, spraying gives a higher plant density and uniformity of panicle bursting date. Main grain is more liable to attack than bosom grain.

Blindness of oats is discussed, and results given to support the theory that one type of blindness is caused by frit fly attacking the immature grain.

10.26. Southwood, T. R. E. (1960). The flight activity of Heteroptera. *Trans. R. ent. Soc. Lond.* **112**, 173–220.

Details are given of the Heteroptera taken in various light and suction traps at Rothamsted, some of which ran for several years, from shorter periods of trapping at Kawanda (Uganda) and Tafo (Ghana), and with suction traps at different heights at Cardington, Beds. The new information provided by the present study on the level of flight activity of various taxa is reviewed. Closely related taxa often differ greatly, e.g., the activity of the Cydnidae as a family is high, of the Pentatomidae, low; that of the genus *Lygus*, high, of *Liocoris*, low; that of *Orthops kalmi* L. high, and of *O. campestris* L. low.

10.27. Taylor, L. R. (1961). Aggregation, variance and the mean. *Nature, Lond.* **189**, 732–735.

Sets of samples from populations at various levels of density were examined to find the relation between the mean and variance. The 24 examples used, aggregated to widely different degrees, are all satisfactorily described by a power law: variance is proportional to a fractional power of the mean ($s^2 = am^b$), in which the power is an Index of Aggregation ranging from 0·70 to 3·08 in the examples cited. The law also gives a general transformation for all degrees of aggregation:

$$f(x) = Q\int m^{-b/2}\mathrm{d}m$$

Bee Department

General Papers

11.1. Butler, C. G. (1961). The efficiency of a honeybee community. *Endeavour*, **20**, 5–10.

11.2. Free, J. B. (1960). Amendments made by F. W. L. Sladen to his book " The Humble-Bee ". *Bee World*, **41**, 8–9.

11.3. Free, J. B. (1960). The pollination of fruit trees. *Bee World*, **41**, 141–151, 169–186.

11.4. Spencer-Booth, Yvette (1960). Feeding pollen, pollen substitutes and pollen supplements to honeybees. *Bee World*, **41**, 253–263.

Research Papers

11.5. Bailey, L. (1960). The epizootiology of European Foulbrood of the larval Honey Bee, *Apis mellifera* Linnaeus. *J. Insect Path.* **2**, 67–83.

Larvae, artificially infected when 0–1 day old with *Streptococcus pluton* (White) and placed in colonies, were usually ejected by adult bees. Ejection was delayed from colonies deprived either of unsealed brood or their queen, or which were reinforced with adult bees. The faeces of surviving larvae whose weight was subnormal contained many viable cells of *S. pluton*. Colonies reinforced with unsealed brood removed more infected larvae than usual. It is concluded that infected larvae are ejected when larval food is merely adequate, as it may be when a colony is growing rapidly; and they are kept when larval food is more abundant, as it may be when brood-rearing is retarded.

Natural outbreaks of disease occurred when brood-rearing, in colonies heavily infected with *S. pluton*, was increasing during nectar flows, which was also when secondary infection with *Bacterium eurydice* (White) increased. At such times larvae heavily infected with both organisms may die more quickly than they are being removed. At the same time infection of new larvae with *S. pluton* seemed to decrease: transmission of *S. pluton* was presumably checked by the death and ejection of unsealed larvae. Thus outbreaks usually seemed to be self-limiting. Colonies eject introduced larvae even more readily after the main nectar flows are over, which may account for the difficulty in causing disease artificially at this time.

11.6. Butler, C. G. (1960). The significance of queen substance in swarming and supersedure in honey-bee (*Apis mellifera* L.) colonies. *Proc. R. ent. Soc. Lond.* (A) **35**, 129–132.

Measurements showed that both superseded and old mated swarm queens from uncrowded colonies contained only about one-quarter as much queen substance as mated laying queens from colonies without queen cells. Old

mated swarm queens from overcrowded colonies had about as much as the mated laying queens.

The demand for queen substance by workers from colonies preparing to swarm was found to be no greater than that by workers from non-swarming colonies.

It appears, therefore, that queen rearing by uncrowded colonies preparing to supersede their queen or to swarm with her results from the queen producing too little queen substance, but that queen rearing in an overcrowded colony before swarming is not necessarily due to inadequate production of queen substance, but could be due to its inefficient collection and distribution.

11.7. Butler, C. G. (1960). Queen recognition by worker honeybees (*Apis mellifera* L.). *Experientia*, **16**, 424–427.

Living queens attract worker honeybees from a short distance on account of an odour they produce, which persists for several months after death. The substance responsible is removed when queens are extracted with ethanol, and the material so extracted is attractive to worker bees. There is reason to believe that its attractive odour is only gradually released from a queen's body.

Queen substance can also be extracted from queens' bodies in ethanol, but pure queen substance (9-oxodec-2-enoic acid) does not have an odour that attracts workers even when offered in large amounts. It is clear, therefore, that queen substance is not responsible for the odour which probably attracts workers to a queen and so helps them to find queen substance, but does not itself inhibit queen rearing.

11.8. Butler, C. G. (1960). Queen substance production by virgin queen honey-bees (*A. mellifera*). *Proc. R. ent. Soc. Lond.* (A) **35**, 170–171.

Little or no queen substance was produced by virgin queens 24 hours old, but virgins 1 week old had significantly more and those 3 weeks old, whether laying or not, had much more but less than well-established mated laying queens. In fact, virgins 1 week old each had about one-quarter as much queen substance as a mated laying queen (i.e., about as much as a superseded queen or a swarm queen from an uncrowded colony) and those 3 weeks old had about one-third as much.

It was concluded that the inability of a virgin queen to inhibit queen rearing, and also perhaps the difficulty of replacing a virgin queen of a colony by a mated laying queen, are probably both due to the low level of queen substance produced by virgin queens. It is clear, however, that colonies do not distinguish between virgin and mated queens by the relative amounts of queen substance on their bodies.

11.9. Free, J. B. & Spencer-Booth, Yvette (1959). The longevity of worker honeybees (*Apis mellifera*). *Proc. R. ent. Soc. Lond.* (A) **34**, 141–150.

Groups of 100 newly emerged worker honeybees were introduced weekly into each of four colonies from March to October and their longevity ascertained. The mean length of life of bees introduced in spring and summer was lower than had previously been supposed. It decreased in accordance with their date of emergence from just over 5 weeks in March to about 4 weeks in June, the weekly death-rate at all ages being greater in June than at any other time.

The weekly death-rate of bees emerging in August was considerably lower than for bees emerging during the previous 3 months. Many bees emerging in August and September overwintered, some surviving until May; there was no correlation between their age and date of death the following year. Some bees emerging in October survived until June. The longest lived bees survived between 217 and 228 days. There were marked differences in longevity of bees from different colonies.

11.10. Free, J. B., Free, N. W. & Jay, S. C. (1960). The effect on foraging behaviour of moving honeybee colonies to crops before or after flowering has begun. *J. econ. Ent.* **53**, 564–566.

Experiments on peach, sweet cherry, apple, bird's-foot trefoil, lucerne and red clover have shown that delaying moving colonies to a crop until flowering has begun increases the proportion of foragers which visit it.

11.11. Simpson, J. (1960). The age of queen honeybees and the tendency of their colonies to swarm. *J. agric. Sci.* **54**, 195.

Analysis of a commercial beekeeper's records showed that colonies with 2-year-old queens are much more likely to have occupied queen cells than those with 1-year-old queens.

Statistics Department

General Papers

12.1. Gower, J. C. (1961). The analysis of experiments on the Rothamsted computer. *Manchester stat. Soc. Group Meetings*, Session 1959–60, 40–49.

12.2. Leech, F. B. (1961). Food losses through animal disease. *Proc. Nutr. Soc.* **20**, 20–24.

12.3. (Pereira, H. C.) & Vernon, A. J. (1960). Practical aspects of field experimentation in Africa. *E. Afr. Agric. For. J.* **26**, 35–41.

12.4. Yates, F. (1961). The use of electronic computers in the analysis of replicated experiments, and groups of experiments of the same design. *Bull. Inst. agron. Gembloux.* (In the press.) (French text: *Biométrie-Praximétrie*, **3–4**, 3–15, (1960).)

Research Papers

12.5. (Bartlett, M. S.), Gower, J. C. & (Leslie, P. H.) (1960). A comparison of theoretical and empirical results for some stochastic population models. *Biometrika*, **47**, 1–11.

This paper is in two sections. The first part establishes a number of theoretical results for stochastic population models in both discrete and continuous time. Models involving one or two species are considered, and formulae for the mean, variance, skewness and where appropriate covariance of the population distributions for stationary distributions are obtained, to both the first and second order of approximation.

Explicit formulae are obtained for the logistic model of population growth, and the second part of the paper compares these formulae with results obtained from numerical sampling experiments on the discrete time model. The agreement between the observed moments and the theoretical approximations for the discrete time model are very satisfactory. As was to be expected, the agreement with the continuous time approximation is not quite so good, but by reducing the discrete time interval the moments for the two models approximate more closely to each other.

Some results are also given comparing numerical results for a system of two competing species. The agreement with theory is again satisfactory.

12.6. Boyd, D. A. (1961). Fertiliser responses of maincrop potatoes: a re-examination of the experimental evidence. *J. Sci. Fd Agric.* (In the press.)

The results of recent manurial experiments on maincrop potatoes were re-examined to determine: (i) what general changes in level of response had occurred since Crowther and Yates' summary in 1940, and (ii) the nature of

the interactions between nutrients and their influence on the form of the fertiliser response curve and on optimal fertiliser dressings.

Average responses to 0·8 cwt. N, 1·0 cwt. P_2O_5 and 1·5 cwt. K_2O/acre in over 100 experiments done since 1940 were 1·8, 1·4 and 2·0 tons/acre respectively, and these do not differ by more than 0·2 tons/acre from Crowther and Yates' figures.

Most of the recent experiments on mineral soils showed large interactions between nutrients which affect both the magnitude of the response to a given dressing and the degree to which the response fell off with increasing levels of dressing. The concept of a "standard" response curve of the exponential form did not adequately describe the response surface revealed in these experiments. Evidence is presented that, for any nutrient, the response curve rises to a maximum and then begins to fall, and that the level of dressing at which the fall begins depends on the amounts of the nutrient present in the soil, on the supply of the other plant nutrients, both by the soil and from fertilisers and farmyard manure, and on other factors, such as the method of fertiliser application.

For fertiliser applied over the ridges at planting, optimal dressings were estimated to be 1·0–1·2 cwt. N and P_2O_5/acre and 1·5–2·0 cwt. K_2O/acre, but the optima were ill determined because the fertiliser rates tested in most of the experiments were too low.

12.7. Boyd, D. A. (1961). Series of experiments. *N.A.A.S. Quart. Rev.* Spring 1961.

The article discusses the planning of local and national series of experiments, dealing in particular with the number of sites and their selection, and the effects of season, and emphasises the importance of field and uniform recording to enable the effects of external factors on the experimental treatments to be assessed. In series of factorial experiments more detailed knowledge of the effects of individual treatment combinations is being sought, and having regard to recent improvements in experimental technique, this suggests that modifications may also be required in some aspects of experimental design and analysis.

12.8. Boyd, D. A. (1961). Current fertiliser practice in relation to manurial experiments. *Proc. Fertil. Soc.* (In the press.)

The paper discusses the use of fertilisers on potatoes, sugar beet and cereals in relation to the fertiliser requirements of these crops indicated by recent experimental results. For the country as a whole, the average rates of application of N, P and K fertilisers for potatoes, N and K fertiliser for sugar beet and N for cereals are probably not far from the average optima; phosphorus requirements of sugar beet are usually small. There is little modern information on the P and K requirements of cereals.

Fertiliser requirements of potatoes and sugar beet differ substantially from district to district, but differences in fertiliser use are small. Within a district, however, there are large differences in fertiliser use from farm to farm, which appear to be largely unrelated to factors known to influence crop requirements, such as soil nutrient status, previous cropping and use of farmyard manure. Potatoes and sugar beet are manured very similarly, but their requirements of P are quite different.

Nitrogen requirements of cereals vary over a very wide range, both from season to season and in relation to such factors as level of soil fertility, previous cropping and manuring and disease incidence. Except that farmers' decisions on whether or not to apply N were to some extent related to previous cropping, it is doubtful if the large variation in practice from farm to farm was related to real differences in response.

12.9. Boyd, D. A., Church, B. M. & Hills, M. G. (1961). Fertiliser practice in England and Wales. Part I. General features of fertiliser consumption, 1956–57. *Emp. J. exp. Agric.* **29**, 35–44.

Results from 35 surveys of fertiliser practice in England and Wales done in 1957 are used to provide estimates of average consumption of N, P and K

within three groups of districts: (1) arable districts, (2) lowland grassland districts, and (3) English uplands and Wales.

Arable farming districts used between two and three times as much N and K per acre crops and grass as the lowland grassland districts, and four to five times as much as the upland districts. Much the same differences were found for water-soluble P, but more basic slag and rock phosphate were used in grassland districts.

Changes in consumption are examined, using the results of previous surveys. Between 1953 and 1957 there were large increases in use of N and K on tillage and leys, mainly, but not entirely, from increases in the proportions of crop acreages treated; the absolute increases were smaller for permanent grass, but as percentages of 1953 consumption were very large, except in upland districts where little change occurred. In general, the proportions of crop acreages receiving P changed little, but where compound fertilisers were replacing the use of straight P, rates of application were much lower.

The total amount of farmyard manure produced in England and Wales in 1956–57 is estimated to have been about 50 million tons, or just under 2 tons/acre of crops and grass. Except for a small increase in lowland grassland counties, there has been little change since a previous estimate in 1944.

12.10. Buck, S. F. (1960). A method of estimation of missing values in multivariate data suitable for use with an electronic computer. *J. R. statist. Soc. B.*, **22**, 302–306.

Estimation of statistical parameters from multivariate data results in wasted information if units with incomplete data are rejected entirely, and perhaps in inconsistencies in the variance–covariance matrix if the variances and correlation coefficients are estimated from all available data on individual variates and pairs of variates respectively. An alternative is to estimate the missing values by regression techniques and to calculate a revised variance–covariance matrix. This method is suitable for use with an electronic computer. It is shown that with this method the resultant covariances are unbiased, but that the variances require correction for bias. A numerical example is given.

12.11. Church, B. M. (1960). An investigation of sampling dried pyrethrum flowers from bulk. *Trop. Sci.* **2**, 200–218.

The general requirements for a reference sampling method, and requirements for acceptable methods of obtaining routine commercial samples from bulk, are briefly discussed.

A reference method is described that gives unbiased samples of dried pyrethrum flowers to provide a standard against which to test routine sampling, and is also suitable for direct use in experimental work. The method is based on the use of " rifflers " which decrease the entire bulk of flowers by repeated subdivision. A method is given for calculating the numbers of samples, and of laboratory determinations per sample, needed to give estimates of required accuracy.

The percentage pyrethrin content of 2–4 lb. reference samples has a standard deviation which is 1½–2% of the mean content. Laboratory errors must also be taken into account when deciding on the accuracy required in sampling. The standard deviation for spectrophotometric determinations on sub-samples from the same sample was also about 1½% of the mean under favourable conditions, but could be substantially greater.

Tests of a sampling machine in routine use showed that it tended to overestimate the percentage pyrethrin content of bulks of flowers by about 0·02 or 1½–2% of the mean. The bias was fairly consistent and not large compared with the random errors of routine determinations. The bias could be accounted for by the fact that the machine, which sampled from a stream of flowers falling from the end of a conveyor belt, collected proportionately more of that part of the stream falling farthest from the belt. Random errors attributable to machine sampling are shown to be small compared with those from sample reduction and analysis.

Some information obtained incidentally on the deterioration of ground pyrethrum flowers is summarised.

12.12. Church, B. M., Boyd, D. A. & Hills, M. G. (1961). Fertiliser practice in England and Wales. Part II. Manuring of cereals. *Emp. J. exp. Agric.* (In the press.)

Detailed information is presented on cereal manuring in England and Wales in 1956–59, and regional trends in practice since 1953 are examined. Over the country as a whole, average N and K consumption per acre of cereals increased by almost half since 1953, while phosphate consumption had changed little.

Within broad farming type regions, the average manuring of cereals in different districts is generally similar. In East Anglia (excluding the fens) and southern England, where all but a small proportion of the cereals received complete fertiliser, average nitrogen dressings to winter wheat were close to the probable optima. Elsewhere a substantial part of the acreage received no fertiliser, and average nitrogen dressings were lower. The scope for increases in use of fertilisers on cereals in these areas is doubtful, because of residual nutrients from previous crops, ploughing in of dung and climatic factors.

Although factors such as previous cropping and methods of fertiliser application are shown to be associated with differences in average manuring, it seems unlikely that the large differences within regions in the manuring of individual farms correspond in general to differences in crop requirements.

12.13. Dobson, R. M. & Morris, M. G. (1961). Observations on emergence and life-span of the wheat bulb fly (*Leptohylemia coarctata* (Fall)) under field-cage conditions. *Bull. ent. Res.* **51**, 803–821.

See no. 10.11 above for summary.

12.14. (Egdell, J. W. *et al.*) & Westmacott, M. H. (1960). Some studies of the colony count technique for soil bacteria. *J. Soc. appl. Bact.* **23**, 69–86.

A series of co-operative experiments compared the bacterial colony counts from soil obtained by workers in different laboratories using soil extract agar and other media for the determinations. The earlier experiments had not given a reasonable degree of reproducibility of results between laboratories even when the plating technique was carefully prescribed.

By modification and more rigid standardisation of the technique, closer agreement of results was obtained. It is suggested that, when co-operative investigations are contemplated, the participating laboratories should check their results by the examination of " control " soils.

No evidence could be obtained to support the suggestion that higher colony counts are obtained by the use of soil extract media containing extract prepared from the same soil as the sample tested. The source appears to be immaterial so long as the soil for extract preparation is not of extreme type and has been well manured and cultivated.

The plate counts obtained from 10^{-5} and 10^{-6} dilutions of the same soils were compared in some experiments. The colony counts for the 10^{-6} dilution, expressed as colonies/g. dry soil, were between $1\frac{1}{2}$ and 2 times those for the 10^{-5} dilution. It is thus clear that counts of soil samples cannot be compared if they have been drawn from different dilutions.

12.15. Gibbs, A. J. & Gower, J. C. (1960). The use of a multiple transfer method in plant virus transmission studies: some statistical points arising in the analysis of results. *Ann. appl. Biol.* **48**, 75–83.

See no. 7.22 above for summary.

12.16. Gower, J. C. (1961). A note on some asymptotic properties of the logarithmic series distribution. *Biometrika.* (In the press.)

Formulae are given to calculate $S(x,R) = \sum_{r=R+1}^{\infty} \frac{x^r}{r}$, the remainder term in

the logarithmic series, which are valid for high values of R, and values of x close to unity. These are of value when dealing with extreme values of the parameters appearing in the logarithmic series distribution such as have arisen in C. B. Williams' recent study of the possible distribution of the number per species for all the insects in the world. Bounds are given for the errors involved when making the recommended approximations.

12.17. Healy, M. J. R., (McLaren, A. & Michie, D.) (1960). Super-pregnancy in the mouse. III. Foetal growth. *Proc. Roy. Soc. B*, **153**, 367–379.

Polytocous mammals show an inverse relation between the number of young in the litter and the size of the young at birth. It has been customary to attribute this to prenatal competition for a limited pool of nutrients in the maternal circulation (Hammond & Marshall, 1952).

The present study was undertaken to subject the traditional theory to quantitative test. Pregnant mice were killed shortly before term and their foetuses were weighed. Some of the pregnancies had resulted from natural ovulation. Others were obtained by inducing superovulation with hormone treatment, some in adults and others in sexually immature females.

Analysis of the foetal weights yielded several results at variance with the predictions of the theory of competition, notably:

1. Foetal growth was more affected by the presence of other foetuses if these were in the same, rather than in the opposite, uterine horn.
2. Foetuses dying in mid-pregnancy, when their nutritional demands would still be small, exerted effects upon the growth of the survivors comparable to those exerted by foetuses surviving the middle period.
3. The signs of nutritional stress exhibited by sexually immature females carrying abnormally large numbers of foetuses were not accompanied by a reduction in foetal weight after due allowance for foetal number.
4. The foetuses occupying the top (ovarian) position in the uterine horn were on average significantly lighter than the others in the same horn.

These results can be better accommodated by an alternative theory of foetal growth (Eckstein, McKeown & Record, 1955) which proposes that the chief regulating factor is the pressure at which maternal blood is supplied to the placenta. Some other observations on foetal growth in mice are cited which are also consistent with the haemodynamic theory.

12.18. Leech, F. B., Davis, M. E., (Macrae, W. D. & Withers, F. W.) (1960). *Disease, wastage and husbandry in British dairy herds: report of a national survey in 1957–58.* London, Ministry of Agriculture, Fisheries and Food.

Records of disease, culling and mortality were obtained from a random sample of the dairy herds of Great Britain, for the 12-month period 1 October 1957 to 30 October 1958. The data were used to calculate national estimates, that is, estimates of the true values of the statistics for the whole population of 132,000 dairy herds. In addition, regional estimates were calculated for eight subdivisions of the country. One of the major items in the report is the description of and comment on the differences between these regional estimates.

The analysis of 14 sets of data concerning size of herd and farm, breed of cow, aspects of management, husbandry and output revealed substantial and, frequently, large regional differences for every set of data.

The data on morbidity are regarded as records of symptoms that were recognised by the farmer or his staff as symptoms that affected, or threatened to affect, the economic value of the animal. The outstanding feature of the diseases of dairy herds was the importance of diseases peculiar to the female, particularly mastitis and those closely associated with parturition. Of the remainder, the most important specific diseases appear to have been Johne's disease, grass tetany and foul-in-the-foot. The incidence of several important diseases differed considerably between breeds, and in herds of different sizes and in different parts of the country.

A characteristic feature of most of the diseases analysed was that they affected a few herds seriously, whereas most herds reported little or none. This situation is characteristic of an infectious disease, but the metabolic diseases and bloat were distributed between herds in precisely the same way, which implies that the unknown factors tending to cause a high incidence of these diseases were distributed over relatively few farms.

The survey data relevant to infertility are briefly discussed.

The information obtained about cows culled from the herds was used to show some of the factors affecting seasonal changes in the size of the national herd, and to estimate the shortening of the productive life and depreciation in the market value of diseased cows.

Although there are many reasons why the earlier data summarised by the Gowland Hopkins Committee are not strictly comparable with the data from this survey, possible comparisons suggest that the health of dairy herds in the last 30 years has greatly improved and has allowed a greater rate of culling for low milk yield and an increase in the numbers of cows reaching that rather nebulous period " old age ".

12.19. (O'Connor, L. K.) & Lipton, S. (1960). The effect of various sampling intervals on the estimation of lactation milk yield and composition. *J. Dairy Res.* **27**, 389–398.

The effect was studied of various sampling intervals on the accuracy of estimating lactation milk yield, fat yield, solids-not-fat (s.n.f.) yield, fat percentage and s.n.f. percentage.

The basic data consisted of daily milk, fat and s.n.f. yields for 18 lactations made by 12 Dairy Shorthorn cows. Estimates of the lactation yields and quality were obtained using 7-, 14-, 28-, 42-, 56- and 63-day sampling intervals, and were expressed as differences from the actual values.

Only with milk yield was there any effective bias in the estimates. This bias increased with increasing sampling interval.

The distributions of differences between estimated and actual values are presented. The error of estimation increased with increasing sampling interval.

Keeping in mind the comparatively small-sized sample used in the investigation, the results are discussed in the light of the purposes for which records are kept.

12.20. Patterson, H. D. & (Lucas, H. L.) (1961). A catalogue of change-over designs. Tech. Bull. *N. Carolina agric. exp. Sta.*

This bulletin presents a comprehensive set of the available change-over designs which take account of first residual effects. The tables of designs are preceded by discussions of the choice and use of the designs. The bulletin also includes details and worked examples of the analysis in which additive constants are fitted for direct and first residual effects. Modified methods of analysis appropriate to some special situations are also described.

12.21. (Pizer, N. H., Wright, H. A., Caldwell, T. H., Hargrave, J., Burgess, G. R., Cory, V.) & Boyd, D. A. (1961). A study of the peat fenlands with particular reference to potato manuring. *J. agric. Sci.* (In the press.)

Peat soils change gradually as a result of drainage and cultivation, losing depth from shrinkage, oxidation and blowing, changing in character through increases in mineral matter and " drumminess ", and changing in productivity and manurial requirements. The sequence of changes was studied in the field and some stages distinguished which may be recognised quite simply from the texture of the ploughed layer. Texture is a field assessment of the type and condition of the peat and the proportion and nature of the mineral matter associated with it. The fenland soils have been classified as follows: (1) peat soils, (2) peaty mineral soils, (3) organic mineral soils, and (4) mineral soils. Further subdivision into textural classes depends on recognising the mineral combinations or fractions as in texturing mineral soils.

Analysis of samples of the ploughed layer in the laboratory showed that

organic matter or loss on ignition figures, expressed as a percentage of the oven-dried soil, can be used to recognise the textural groups, and use is made of this in considering those earlier experiments for which organic matter figures could be calculated.

Thirty-eight experiments of the standard 3 × 3 × 3 design, testing the effects of N, P and K fertilisers on maincrop potatoes, were made in the peat fenlands in the years 1952–56. The main influence of the kind of soil was on total yield and response to potassium. The mean yields were considerably less on the peat soils than on the peaty mineral and organic mineral soils. The responses to N were substantial in each soil group, but less on the peats than on the peaty mineral and organic mineral soils. The responses to N were surprising in view of the organic nature of the soils. All soil groups responded better to P than to N, and past generous manuring with superphosphate seemed to have little effect on response. Responses to K were highest on the peats and fell off progressively through the peaty mineral and organic mineral soils; on soils containing relatively little organic matter and a correspondingly high proportion of clay minerals, there was evidence that potash caused a small but definite decrease in yield. Nitrogen and potash responses were greatest in 2 years with little blight and least in 2 years when blight was severe.

Tuber size was lessened by the application of phosphate, moderate dressings having much the same effect as large ones; nitrogen and potash had little effect. Growth of tops was greatly stimulated by phosphate, the effect being most noticeable during June and decreasing afterwards; the nitrogen had little effect during June, but substantially increased top growth during July and early August; the effect of potash was small.

The value of soil analysis in predicting responses to phosphate and potash is discussed. Recommendations are made for the manuring of potatoes on peat fenland soils.

12.22. Potato Marketing Board, Rothamsted Experimental Station & The National Institute of Agricultural Engineering (1960). *Report on the survey of maincrop potatoes. 1958*: Potato Marketing Board Report.

A survey of 971 farms was done in 1958 to provide information on current farm practices for maincrop potatoes, with particular reference to the use of machinery. Information is given on cultivations, planting and harvesting methods, seed types and rates, fertiliser and spraying practice, and storage, making comparisons with previous survey results.

Three-quarters of the maincrop acreage was machine-planted in 1958, compared with a third in 1948, but the total acreage declined by almost half during this decade. There has been a trend towards deeper ploughing, and more than a third of the 1958 acreage was ploughed to a depth of 11 inches or more. 57% of the acreage was planted with certified seed, 41% with once-grown seed and 2% with seed grown twice or more. In most parts of England the proportion of certified seed was rather smaller than in 1948. Seed rates had changed little and were heavier for certified than uncertified seed.

In 1958, a severe blight year, half the acreage was sprayed, usually with copper-based chemicals, and almost a quarter of the treated acreage was sprayed from the air. 58% of the acreage was lifted by spinners, 33% by elevators and only 5% by complete harvesters. Three-quarters of the farms depend on seasonal labour for picking.

The survey estimate of average yield, based on lifting random lengths of row, was 7·7 tons of sound potatoes/acre, compared with an independent Ministry of Agriculture estimate of 7·1 tons/acre based on crop reports.

12.23. Simpson, H. R. (1961). The analysis of survey data on an electronic computer. *J. R. statist. Soc. A.* (In the press.)

This paper describes the lessons learnt from experience of programming survey analyses for the Rothamsted computer. The difficulties of handling large quantities of data, especially on small computers, are discussed, and a general programme for the analysis of surveys is described.

12.24. (Tanner, J. M.), Healy, M. J. R., (Whitehouse, R. H. & Edgson, A. C.) (1959). The relation of body build to the excretion of 17-ketosteroids and 17-ketogenic steroids in healthy young men. *J. Endocrinol.* **19**, 87.

The excretions of 17-ketosteroids, 17-ketogenic steroids and creatine from 101 medical students were measured and compared with assessments of body build based on anthropometric measurements, somato typing and on limb widths of fat, muscle and bone. Week-to-week variations in individuals' excretions were taken into account in assessing relationships. The main conclusions drawn are:

1. Individual level of 17-KS and 17-KGS excretion are inversely related, especially when allowance is made for body size.
2. 17-KS excretion is related to body weight, mesomorphy and muscle width.
3. 17-KGS excretion is related to weight and height, via the widths and lengths of the limb bones. There is no relation with muscle width or with subcutaneous fat.

The implications of these conclusions are discussed.

12.25. Yates, F. (1961). Marginal percentages in multiway tables of quantal data with disproportionate frequencies. *Biometrics*, **17**. (In the press.)

When multiway tables of quantal data are analysed by transforming the percentages and fitting constants to the transformed variate by the method of maximum likelihood, direct inverse transformation of the values of the fitted constants gives percentages which may deviate widely from those observed. The reasons for this are explained, and methods are given for obtaining correct percentages.

12.26. Yates, F. & Simpson, H. R. (1960). A general programme for the analysis of surveys. *Comput. J.* **3**, 136–140.

A programme for the analysis of surveys, written for the Elliott 401, is described. In spite of the small size of the machine, it has been possible to develop a general programme which can perform the very varied operations that are commonly required in the analysis of survey material.

12.27. Yates, F. & Simpson, H. R. (1961). The analysis of surveys: processing and printing of the basic tables. *Comput. J.* (In the press.)

This paper describes the second part of a general programme for the analysis of surveys, written for the Elliott 401 computer. Part 2 of the programme processes and prints the tables generated by Part 1, which was described in 12.26.

Dunholme Field Station

General Papers

16.1. Adams, S. N. (1960). Sugar-beet fertiliser experiments in 1959. *Min. Agric. Sugar Beet Res. & Educ. Comm. Pap.* 569.

16.2. Adams, S. N. (1960). Fertiliser trials with sugar beet. 1. The "Types of Nitrogen" experiments. *Brit. Sugar Beet Rev.* **28**, 175–176.

16.3. Adams, S. N. (1960). Sodium and sugar beet. *Brit. Sugar Beet Rev.* **29**, 18.

16.4. Adams, S. N. (1960). The effect of different forms of nitrogen on sugar beet, and the value of late top-dressing. *Rep. 23rd Winter Congr. int. Inst. Sugar Beet Res.*, Brussels 1960, 283–288.

16.5. Byford, W. J., Dunham, E. C., Dunning, R. A., Heathcote, G. D., Hull, R., & Winder, G. H. (1960). Sugar-beet disease investigations, 1959–60. *Min. Agric. Sug. Beet Res. & Educ. Comm. Pap.* 575.

16.6. Dunning, R. A. (1960). Virus yellows: the need to look ahead. *Brit. Sug. Beet Rev.* **29**, 37–40.

16.7. Dunning, R. A. (1960). Pest populations, especially virus vectors, and productivity of sugar beet. XI International Congress of Entomology, Vienna, August, 1960.

16.8. Hull, R. (1960). A new factor in sugar-beet growing. *Brit. Sugar Beet Rev.* **28**, 113–132.

16.9. Hull, R. (1960). Sugar-beet yellows in Great Britain, 1959. *Plant Path.* **9**, 151–152.

Research Papers

16.10. Adams, S. N. (1961). The effect of time of application of phosphate and potash on sugar beet. *J. agric. Sci.* **56**, 127–130.

Twenty-nine experiments on sugar beet in 1957–59 compared ploughing-down of phosphate and potash in the previous autumn with spring application before the seedbed preparations.

On average, spring application gave a higher yield of sugar and tops than ploughing-down both in the wet summers of 1957 and 1958 and in the dry summer of 1959.

Plants on plots where fertiliser was broadcast in spring usually grew quicker early in the season, which is probably why this method of application was superior. In 1959, with a starter dose of phosphate and potash in the seedbed, ploughing-down was almost as effective as broadcasting.

16.11. Adams, S. N. (1961). The effect of sodium and potassium on sugar beet on the Lincolnshire limestone soils. *J. agric. Sci.* **56.** (In the press.)

Seventeen experiments in 1957–59 on the Lincolnshire limestone soils tested the response of sugar beet to 1·5 cwt. K_2O/acre as muriate of potash and its chemical equivalent of sodium chloride (1·8 cwt./acre). Average response of sugar beet to sodium was higher than to potassium, especially in the wet summer of 1958. There was a negative interaction between sodium and potassium.

Although trials were confined to similar soils, the response to fertiliser varied widely in different experiments. Exchangeable soil potassium extracted by *N*/10-nitric acid, although not by *N*-ammonium nitrate, predicted potassium response to some extent. There was a close correlation between response to sodium and to potassium, so soil potassium also predicted response to sodium. Exchangeable soil sodium did not predict the response to fertiliser.

The rate of sodium chloride used never visibly impaired germination. On average, sodium increased plant population, and the increases in plant population were significantly correlated with response to sodium and to the superiority of sodium over potassium. On some fields, weed control by sodium chloride may account for its raising sugar yield more than potassium.

16.12. Adams, S. N. (1961). The effect of sodium and potassium fertiliser on the mineral composition of sugar beet. *J. agric. Sci.* **56.** (In the press.)

This paper summarises work by the late J. B. Hale, who analysed plants from salt and potash fertiliser trials at Rothamsted, harvested at invervals throughout the growing seasons of 1942 and 1943, for N, K, Na, Ca, Mg and Mn.

The uptake of nutrients is discussed with respect to field methods of fertiliser application.

Salt increased beet yield in both years, but it did not act by mobilising soil potassium reserves and increasing the potassium status of the plant. Potash fertiliser, although increasing the potassium status of the plant, did not increase yield. Sodium and potassium were differently distributed in the plant. At harvest, only 6% of the plant's sodium content was in the root compared with 33% of the potassium. The potassium, but not the sodium, content of the petiole was higher than that of the lamina until the end of August. Sodium thus is a nutrient for beet and not a potassium substitute.

16.13. Dunning, R. A. (1960). Seed and soil treatment with systemic insecticides for control of beet pests, especially vectors of virus yellows. *Rep. 23rd Winter Congr. int. Inst. Sugar Beet Res.*, Brussels, 1960, 429–433.

When used as seed dressings, the systemic insecticides phorate (diethyl ethylthiomethyl dithiophosphate) and "Disyston" (diethyl ethylthioethyl dithiophosphate) control foliage pests after sugar-beet seedlings emerge, but, at rates of dressing necessary for useful insecticidal persistence, they often damage the plants. Granular formulations, applied to the soil or foliage, are not so phytotoxic and their insecticidal effect persists.

16.14. Dunning, R. A. (1961). Mangold fly: its incidence, economic importance and control. *Plant Path.* **10**, 1–9.

Attacks by mangold fly are most frequent in coastal regions and in the North and West, and occurred especially in 1947 and 1954–55. Insecticides are recommended on the results of comparative tests. The use of materials that are also aphicidal is advised when aphids are present, especially in areas where virus yellows is important. Yield trials show that control of mangold fly is economic in England only when backward beet are severely infested.

16.15. Hull, R. (1960). The selection of sugar-beet varieties for tolerance to virus yellows. *Rep. 23rd Winter Congr. int. Inst. Sugar Beet Res.*, Brussels, 1960, 407–417.

Lines of sugar beet that tolerate yellows were obtained by self-pollinating plants which had been selected for yield from plots of commercial varieties with yellows. They gave up to 20% more sugar yield than commercial varieties in the field when yellows was severe, but less when free from yellows. A hybrid between two tolerant lines had a greater leaf area and net assimilation rate than variety Sharpes E when infected with yellows. Yellows decreased the yield of the hybrid by 35% and of Sharpes by 65%. Most roots of Sharpes E with yellows weighed about 400 g., but occasional roots weighed over 1,000 g., so that the distribution diagram of root weights was asymmetric. The root weights of the hybrid when infected had a more normal distribution, with the mode about 700 g. and the maximum 1,500 g.

Soil Survey of England and Wales

17.1. *The soils and land use of the district around Rhyl and Denbigh.* (Sheets 95 and 107). London: H.M. Stationery Office, 1960.

17.2. *Soil map of Beaumaris*, Sheet 94 (3rd Edn.). Southampton: Ordnance Survey, 1960.

17.3. Crampton, C. B. (1960). Petrography of the Mesozoic succession of South Wales. *Geol. Mag.* **97**, 215–228.

The heavy mineral suites of the Trias, Rhaetic and lowest zones of the Lower Lias in the Vale of Glamorgan are described. The northerly coastline of the Mesozoic sea, roughly coincident with the present periphery of the Coalfield, consisted mainly of Carboniferous Limestone and, in places, the Old Red Sandstone and Millstone Grit. The assemblage at any point in the littoral zone was largely determined by the nature of the outcropping rocks of the

coast, the derivation of detritus being very localised. In this zone some degree of gravity sorting of the detritals occurred, implying a steeply inclined coastal sea-bed. An off-shore current carried detritus from the Armorican land-mass of Brittany and granite of South-West England to this area where the detritals were dispersed thinly throughout the locally derived sediment.

17.4. Crampton, C. B. (1960). Analysis of heavy minerals in the Carboniferous Limestone, Millstone Grit and soils derived from certain glacial gravels of Glamorgan and Monmouth. *Trans. Cardiff Nat. Soc.* **87**, 13–22.

An attempt was made to amplify the knowledge of the heavy mineral assemblages of local rock strata by examining the Carboniferous Limestone and Millstone Grit as a prelude to investigating the mineral suite of drift soils developed on glacial sands and gravels in Glamorgan and Monmouthshire. The soil profile shows no marked change throughout the area investigated. Material from the Coalfield constitutes an important part of the parent material, and the Irish Sea Drift a small but consistent element. To the east of the area material from the Old Red Sandstone has also been incorporated, and to the west material from the Millstone Grit, and to a lesser extent, from the Carboniferous Limestone. Local ice flows travelling across the Coalfield from the north would produce these mixed superficial deposits.

17.5. Crampton, C. B. & Webley, D. (1960). The correlation of prehistoric settlement and soils in the Vale of Glamorgan *in* III Archaeology and Art. *Bull. of the Board of Celtic Studies*, **18**, 387–396.

Prehistoric settlement in the Vale of Glamorgan has been correlated, age by age, with the distribution of various soils mapped during routine soil survey of the County of Glamorgan. Neolithic and Bronze Age man preferred the freely drained soils on the various limestones. The evidence suggests that Neolithic man placed his burial mounds as far as possible from the settlement areas, and near the boundary of the free draining soils with the impeded soils. The tombs of the Middle Bronze Age are, however, more dispersed over the limestone outcrop; some must have been near the settlements. Migration on to the freely drained sandy soils over Glacial drift becomes greater during the Bronze Age, but it was only during the Iron Age that these soils were extensively exploited. It remained for the Romans to exploit the heavier impeded soils, previously ignored.

17.6. Mackney, D. (1960). Soils and soil maps. *N.A.A.S. quart. Rev.* no. 46, 47–52.

A semi-popular account of soil morphology and the preparation of soil maps with some explanation of their uses and a plea for co-operation in deducing productivity ratings of soils.

Library

18.1. Boalch, D. H. (1961). Current literature on agriculture in tropical and sub-tropical countries. *Brit. Book News*, 245, 1–6.

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(obtainable from the Librarian)

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Catalogue of the printed books on agriculture published between 1471 and 1840, by Mary S. Aslin. (Rothamsted, 1926.)*
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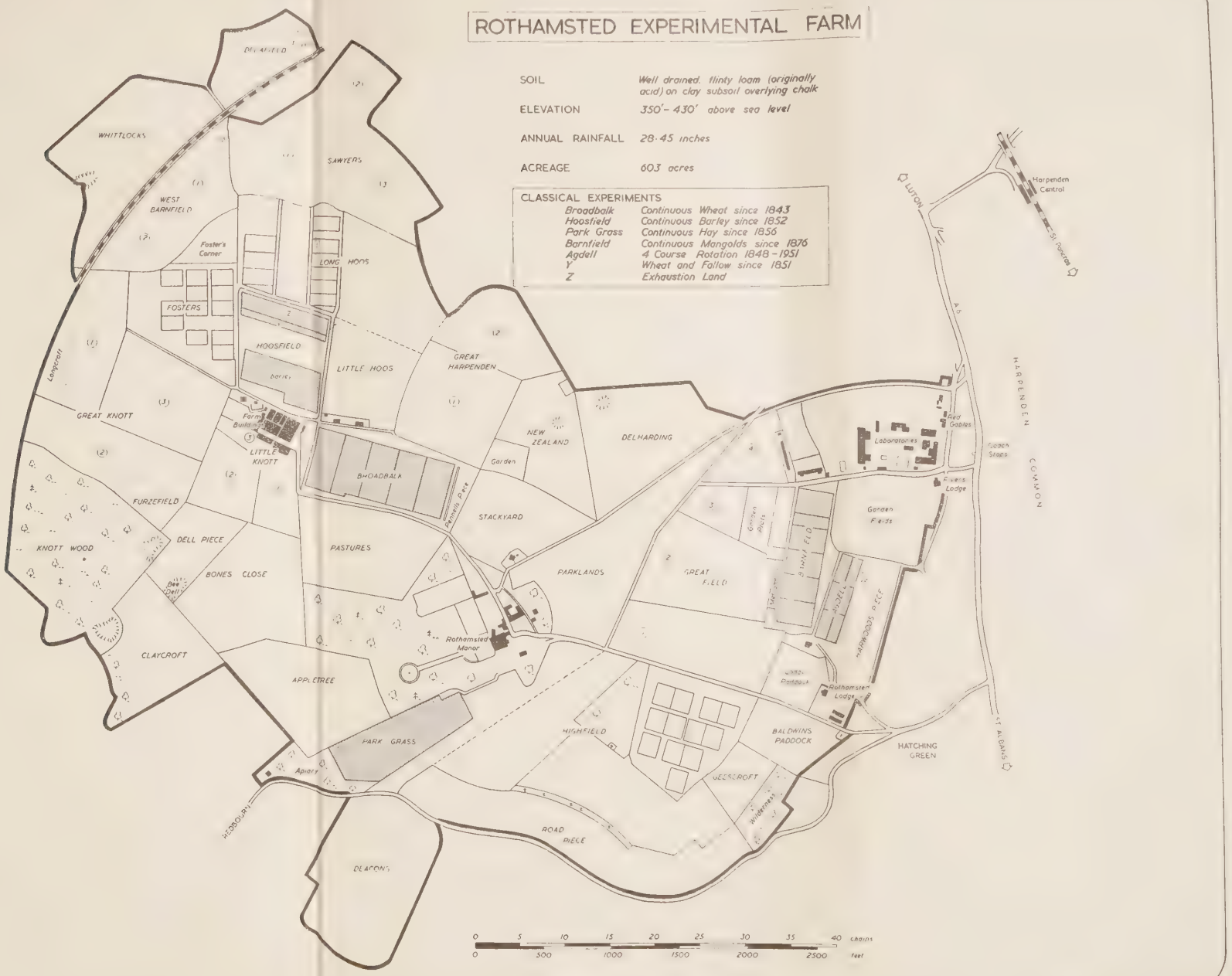
ROTHAMSTED EXPERIMENTAL FARM
SOIL
Well drained, flinty loam (originally acid) on clay subsoil overlying chalk
ELEVATION
350'–430' above sea level
ANNUAL RAINFALL
28·45 inches
ACREAGE
603 acres
CLASSICAL EXPERIMENTS
Broadbalk Continuous Wheat since 1843
Hoosfield Continuous Barley since 1852
Park Grass Continuous Hay since 1856
Barnfield Continuous Mangolds since 1876
Agdell 4 Course Rotation 1848–1951
Y Wheat and Fallow since 1851
Z Exhaustion Land
DEADMANFIELD
WHITTLOCKS
SAWYERS
WEST BARNFIELD
Foster's Corner
LONG HOOS
FOSTERS
HOOSFIELD
barley
LITTLE HOOS
GREAT HARPENDEN
Longcroft
GREAT KNOTT
Farm Buildings
LITTLE KNOTT
NEW ZEALAND
DELHARDING
Garden
BROADBALK
Drainage Pipe
STACKYARD
FURZEFIELD
KNOTT WOOD
DELL PIECE
PASTURES
Bee Dell
BONES CLOSE
PARKLANDS
GREAT FIELD
CLAYCROFT
Rothamsted Manor
APPLETREE
PARK GRASS
Apiary
HIGHFIELD
BALDWINS PADDOCK
JEFFCROFT
Wilderness
ROAD PIECE
BEACONS
HEBDON RD
LUTON
Harpenden Central
St. Pancras
Red Gables
Laboratories
Garden Steps
HARPENDEN COMMON
Lawes's Lodge
Garden Plots
Garden Fields
BARN FIELD
AGDELL
HARPENDEN SIDE PIECE
Rothamsted Lodge
HATCHING GREEN
ST ALBANS
0 5 10 15 20 25 30 35 40 chains
0 500 1000 1500 2000 2500 feet

1058

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OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1961

20 JUN 1962